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LAUNCHING OF THE NEW DIESEL-ELECTRIC FERRY BUILT FOR THE TRUSTEES OF THE CLYDE NAVIGATION.
This new ferry will be used for the transport of passengers and vehicles across the Clyde at Glasgow, the passage occupying approximately 3¼ minutes. The ferry has two propellers at each end, driven by separate D.C. motors supplied with current from Diesel engine driven generators. It is hoped to give a full description of the electric propulsion scheme in an early issue of the G.E.C. Journal.

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Recent Progress in Power Rectifiers and Their Applications.

PART I.

By W. G. THOMPSON, Ph.D., B.Sc., A.M.I.E.E.
G.E.C. Mercury Arc Rectifier Works, Witton.

The accompanying article was given by the author as a paper before the Institution of Electrical Engineers on March 17th, 1938. In it he gives a general survey of the present stage of development of power rectifiers. Recent innovations in the design of rectifier types are described, and some of the limitations discussed.

The subject matter of Part I concerns mainly rectifiers of the mercury arc type, including water-cooled rectifiers, glass bulb rectifiers, pumpless air-cooled steel tank rectifiers, and igniter types. These various rectifiers represent a voltage range from 200 volts to 50 kV d.c., and currents up to about 10,000 amperes. Reference is also made to some of the leading non-vacuum rectifiers, such as jet wave rectifiers, gas-cooled arc types and electrolytic and mechanical types. Most of these are still in course of development and an indication of the progress achieved is given. In Part II the more direct methods of controlling the output of the mercury arc rectifiers by means of control grids are mentioned, and in this connection voltage regulation, inversion and arc suppression are discussed.

1. INTRODUCTION.

THE introduction of the arc rectifier into power engineering may be considered to mark the beginning of a new stage in electrical development. Not only has the engineer had to extend the scope of his technical knowledge to include a field of electron phenomena hitherto regarded as subject matter for the physicist, but he has also had to adapt to engineering practice much of the vacuum technique of the physical laboratory. The steady progress of rectifier installations during the last twenty years is indicative of the effective manner in which the new knowledge has been applied. Some outstanding assets of the rectifier are its static nature, robust construction, efficiency and low cost. The extent to which these factors have influenced the selection of rectifier converting plant can be seen from the growth of installed rectifier kW during recent years. This demand has been steady and progressive and shows no immediate signs of diminution; over 4,000,000 kW of rectifier plant is in operation throughout the world.

With a preponderance of installed rectifier plant, competition ceases to be one between rectifier and rotating machinery, but between different types and makes of rectifier. From the technical standpoint every detail needs consideration. The reliability, efficiency and manufacturing costs have only very narrow margins in which further improvements can be effected, so that for any given application the merits and suitability of the rectifier equipment as a whole require careful study.

With one or two exceptions, recent progress in rectifier practice has been by the way of improvement and simplification of existing types, rather than the result of innovations. It is true that novel principles have been applied in connection with the more experimental equipments, though some years may elapse before they become adopted in practice.

The objects of the present paper are to give a general account of the more notable developments in connection with

rectifiers, and to discuss the scope of the available types of rectifier plant in relation to present day requirements.

2. CLASSIFICATION OF RECTIFIER TYPES.

To appreciate the present position, it must be recognised that at the moment power rectifiers are divided into two main groups :—

(*a*) Vacuum, or more strictly, low pressure vapour apparatus.

(*b*) Non-vacuum types.

By far the greater amount of the installed equipment is of the vacuum type, but much active experimental work is being carried out on alternative

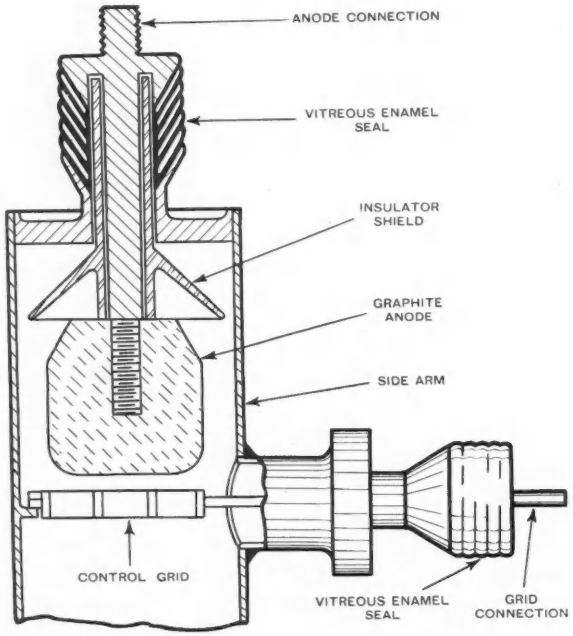


Fig. 1.—Victric seal assembly for grid control of pumpless rectifier.

forms of rectifiers. It is by no means certain that the present almost exclusive use of vacuum equipment will persist indefinitely in the future. On the other hand, it must be admitted that the position of the mercury arc rectifier is an extremely strong one.

Power rectifiers of the first group are all of the mercury vapour type, and are met with in several forms :—

1. Hot cathode rectifiers.
2. Air-cooled mercury pool types.
3. Water-cooled mercury pool types.
4. Igniter types.

The first group favours either glass or glass and metal construction of the vacuum vessel; the second all glass or all metal. All metal is preferred in the third group, while the igniter can be either of glass or of metal construction. Of these different groups, the air-cooled all-metal design and the igniter types represent the most recent progress in their respective fields. An attractive feature of the mercury vapour device is the possibilities of so-called grid control. This is dealt with in a subsequent section, but it may be mentioned in passing that this has been applied in the first three groups with the object of retarding the striking of the power arc in the rectifier until a desired moment in each half cycle. The igniter type, however, embodies the reverse process and positive means are taken to ignite the arc at the desired moment with respect to the a.c. wave.

In general the common cathode types classified under the second and third headings are more particularly suitable for continuous heavy current working, but as a result of the voltage-current characteristics, the maintenance of the cathode spot at light load periods has to be assisted by auxiliary anodes. There are many instances where the various types overlap in their working range and may be regarded as competitive.

Considering now the non-vacuum types, these may be listed as follows[1] :

1. Mercury jet apparatus.
2. Gas-cooled arc types.
3. Hydrionic converters.
4. Mechanical rectifiers.

Most of the non-vacuum rectifiers are merely synchronous interruptors and are free from polarity limitations, but generally involve numerous auxiliaries or rapidly moving parts. On the whole their efficiency, reliability and economy are lower than those of the mercury vapour devices.

It has been found possible in most of the non-vacuum rectifiers to produce the analagous effect to "grid control" featured in the mercury arc rectifiers. The action is usually of a positive type since the initiation of the conducting period is dependent upon auxiliary means, and not upon the removal of the screening effect of the grid. It is only necessary to advance or retard the timing of the auxiliary ignition device to produce the corresponding change at starting of the conducting period in the working portion of the cycle. The mechanical inertia associated with the moving parts of these types of rectifier does tend to produce commutation difficulties, especially when attempting inverted operation. Partly for this reason the application of an auxiliary supply to give so-called harmonic commutation has been put forward in several instances.

3. COMMERCIAL DESIGNS.

Hot Cathode Rectifiers.

Although fundamentally it is easier to obtain

1 Strictly speaking this list should perhaps include copper oxide rectifiers, which in sufficient aggregate can give a large power output; to keep the paper within reasonable length, the term "power rectifiers" has been taken to apply to the individual units.

very heavy currents from a mercury pool cathode, technical advances have made it possible to make hot cathode rectifiers for outputs up to 275 amperes at 7,500 volts. At the other end of the scale, hot cathode rectifiers have been produced for X-ray applications which have outputs of several hundred milliamps at 100,000 volts.

The most common use at the moment is for anode supplies in wireless stations, and for such work there is a series of rectifiers whose range extends from an output of 1,000 volts 500 milliamps up to outputs of 20 amps., 20,000 volts. There are several sets in operation at various radio stations delivering about 10 kV, 10 amps. from a 3 phase full wave circuit. The reliability of such equipments can be very high, arc backs being met only at the end of life and the lives being of the order of 4,000 to 10,000 hours.

These rectifiers almost invariably employ oxide cathodes owing to their great efficiency. The power taken by the cathodes varies considerably between different makers, but generally speaking a 3 phase full wave equipment having an output of 12 amps. at 10,000 to 20,000 volts will have a total cathode power of about 600 watts. As is generally known, the anode-cathode drop when passing current is about 8 to 14 volts.

Thus it is clear that such equipments have very high efficiencies.

Since the valves depend for their operation upon the presence of mercury, it is not surprising that they must be operated between certain limits of mercury pressure. Since the space within the valve is saturated with vapour from a quantity of liquid mercury, the mercury pressure depends on the temperature of the coldest part of the valve.

For the small tubes the temperature range is wide and no special precautions are needed in temperate climates. In the larger tubes, the range is often narrower than the temperature range of the enclosure in which they operate. In such cases temperature control must be employed, and this often consists of a system of air blasts directed at the base of the rectifiers.

The air is maintained at the required temperature by a thermostat and heater.

This type of valve can also be made with the anode system not exposed but completely enclosed in a glass vacuum vessel, but here they are entirely dependent upon radiation for the dissipation of the anode losses, and the rating of the valves is correspondingly reduced. Mention might be made at this stage of a very interesting all-metal hot cathode rectifier, designed for an output of 600 amps. low voltage, but although this was brought out a year or two ago, the line of development does not appear to have been continued.

Mercury Arc Rectifiers.

Notwithstanding the large number of mercury pool type rectifiers produced in recent years and the wide experience gained, the production of a successful design is a matter of compromise between the different variables involved.

Recent tendencies in the development of mercury arc rectifiers are to extend the upper limits of voltage in the few cases where the demand exists, to render grid control as effective as possible, and to

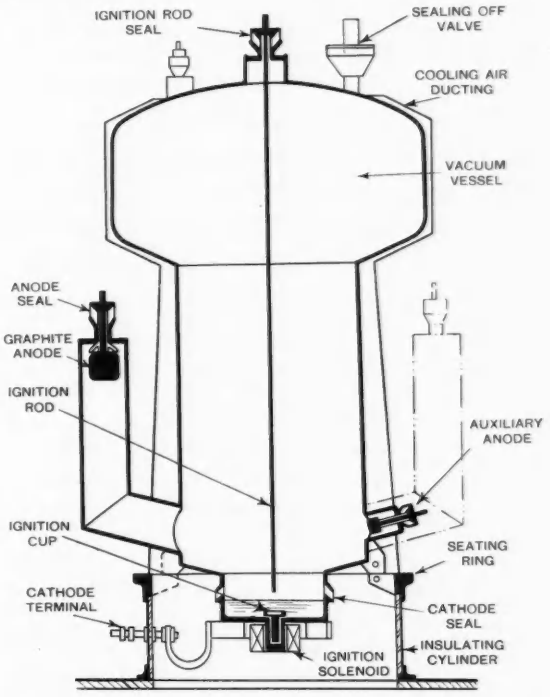


Fig. 2.—Arrangement of pumpless air-cooled steel tank rectifier (600 volts, 550 amps.).

make further use of air cooling. The general trend of application is in the direction of operating convenient sized units in parallel rather than employing large single units with numerous anodes. It is true that in certain cases rectifiers with eighteen and even more anodes are used, but this is done rather with the view of reducing the intensity of the anode loading, than to obtain an enormous output from a single cylinder. The reasons for this will be discussed later.

In the smaller sizes of rectifiers it has been found possible to dispense with a number of the auxiliaries, so that where conditions of space are limited the grouping of small units is often preferred to a more elaborate unit of large output. Thus, even in connection with fairly large capacity substations the air cooled rectifiers are not without significance.

The air cooled mercury pool type rectifier is manufactured both in the glass bulb and in the steel tank forms. Completely sealed off commercial

rectifiers of the latter type are made in this country, and various foreign firms supply a limited range of air cooled rectifiers fitted with the usual vacuum pumps.

Glass Bulb Types.

The glass bulb mercury arc rectifier has few auxiliaries and the usual method of suspension is in steel cubicles. Various attempts have been made to increase the current output of these rectifiers and attention has been directed to the theories underlying their design. To meet temperature requirements, heat resisting kinds of glass are used, the various glasses have a softening point from 650°C. to 1,100°C. and a coefficient of expansion of 140×10^{-7} per degree Centigrade; molybdenum anode connections are fused through the glass. The anodes of a rectifier tend to reach a high temperature, and cooling of the glass anode arms has received special study, but their diameter of cross section is limited by deionisation considerations. It has also been shown that internal cooling can increase the output of these rectifiers. This is not a practicable solution and recourse has had to be made to improved fan design. The power to drive the fan, even for the largest sizes, does not exceed 1 kW, and in a given case the application of a fan increased the bulb output by 150 per cent. Improved ventilation has made units of 500 amperes d.c. output possible, while experimental units have even been loaded to 1,000 amperes. Despite these facts, however, the general policy appears to be that of derating the bulbs to more modest outputs for the sake of reliability. A mean current of 200 amperes per anode has been suggested as a safe working value.

Tests have shown that there is a useful limit to the size and height of dome for a given cathode area, the leading dimensions of a 400 ampere bulb being cathode diameter 14 cms., dome diameter 47·5 cms., and height 85·5 cms. The glass construction makes the attachment of additional cooling devices, such as radiators, baffles, etc., costly, whilst the imploding atmospheric load constrains the designs to spheroidal forms with a low surface-volume ratio. As the units are comparatively cheap, however, the economic policy is to add an extra bulb in parallel, rather than elaborate the units to increase their output. The units are generally constructed with six anode arms and with control grids, if required.

In the event of very large power outputs being required, it is necessary to arrange for a sufficient number of glass bulb units to be mounted in parallel, and substation capacities up to 6,500 kW have been thus obtained.

Another line of glass bulb development is in the high voltage field, where these rectifiers have been made to operate at voltages up to 20 kV. This implies a reverse voltage of about 40 kV and calls for special arrangement of the grids in front of the anodes and a lengthening of the anode arms. The current rating of the rectifier is reduced to about 10 amperes and the practice is to arrange nine arms in each bulb, six of these being in use at any one time. Each anode consists of a short rod and is terminated with suitable electrostatic shields to meet the high voltage conditions.

Mention might be made at this stage of one feature of the completely sealed off rectifiers of the mercury pool type where considerable ingenuity has been expended, namely the igniting of the rectifiers. To start a rectifier and to enable its auxiliary anode to pick up current, it is necessary to produce an electron emitting region on the surface of the mercury pool cathode with the aid of some form of electric discharge. The criteria of a suitable device for this purpose are that it shall be rapid and effective in action, but without putting undue strain on the glass. Several methods have been developed from time to time, and amongst those which have survived and remain in use are:—

1. Making use of a local circuit formed actually with the mercury and introducing a heavy current in the circuit to break it under the combined action of fusing and pinch effect.
2. Introducing vertical motion in a small column of mercury to make momentary contact with an energised ignition electrode.
3. Using a bi-metal strip which is heated and deflects.
4. Using an external solenoid coil to operate a flexible dipping electrode.

Steel Tank Air-Cooled Rectifiers.

The lower economic limit for the water-cooled steel tank rectifier is about 1,000 amperes. It was recognised that if the efficiency could be maintained and the number of auxiliaries reduced, the steel tank would fulfil many applications for currents of the order of 500 amperes.

Commercial rectifiers of the air-cooled pattern with pumps have been produced in a very compact arrangement, but the general design adopted resulted in the current range in this rectifier being only about 170 to 400 amperes.[2] To save space the vacuum pumping gear is mounted on the same bedplate as the rectifier, but underneath the cylinder. A system of ducting constrains the cooling air to the walls of the cylinder.

Pumpless Rectifiers.[3]

Attempts have been made over a number of years to produce a successful steel tank rectifier that

2 Brown Boveri Review, May 1936.

A. Siemens and A. Bower. "Small Steel Tank Mercury Arc Rectifiers With Air-cooling." Siemens Zeitschrift. No. 17, 1937, p. 525.

3 H. W. Richardson. "Electrical Progress and Development—Mercury Arc Rectifiers." G.E.C. Journal, Vol. VII, February 1936, No. 1, p. 7.

would not require pumping at intervals during its life. The early efforts failed largely on account of welding difficulties and because of the absence of leakage detecting methods which could be used under ordinary manufacturing conditions. With improvements in welding, and in particular the development of the atomic hydrogen welding process, coupled with a better understanding of the diffusion of gases through metal containers, it became possible to construct perfectly vacuum-tight vessels.

around which are arranged the anode arms and the auxiliary ignition anodes. As the result of the adoption of the side arm construction, with arm temperatures of over 200° Centigrade, a very effective dissipation of heat from the anodes can be obtained, thus permitting a high rating of the rectifier. The all-metal construction makes for robustness and ability to withstand mechanical shock which is fully borne out in practice. In addition to this, it permits the oblate dome construction with a large

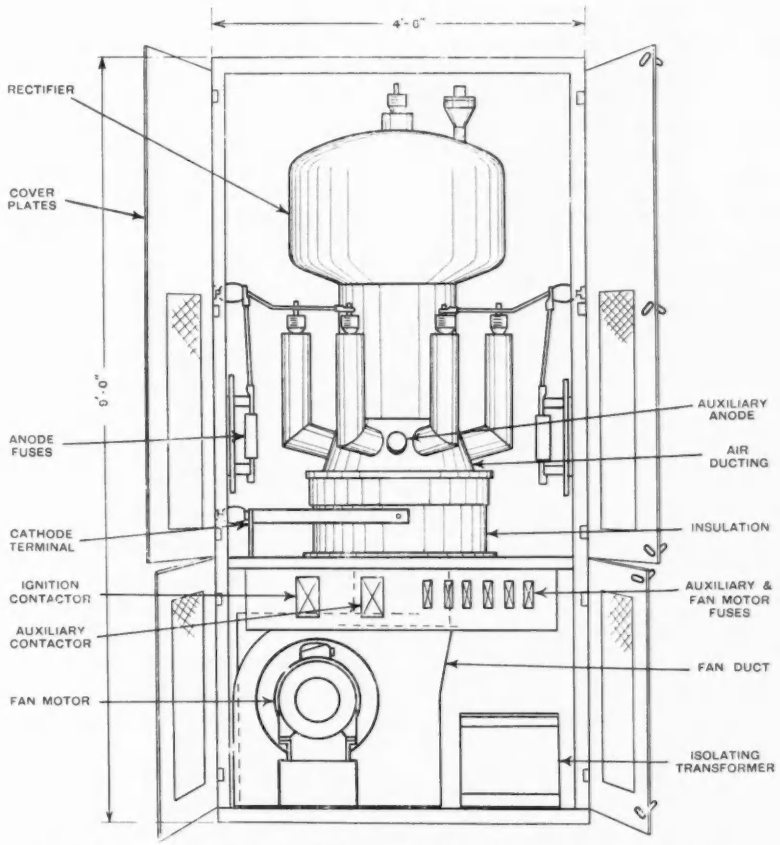


Fig. 3.—Typical arrangement of an air-cooled rectifier in a cubicle.

The problem of anode and cathode insulation had already been solved by the development of the vitreous enamel seal (see fig. 1), and the fitting of a suitable vacuum tight sealing device rendered the all-metal pumpless rectifier a practical proposition. In order to determine whether the continuous "cleaning up" process resulting from the arc was essential to the effective working of the pumpless rectifier, one of the vessels was sealed off and operated after long intervals over a period of two years. No deterioration of the vacuum was found, so that the rectifiers are perfectly suitable for working where intermittent loading is likely.

The general arrangement of the pumpless unit is shown in fig. 1, and consists of a central dome

surface volume ratio, facilitates the external attachment of radiators and air baffles, and renders possible the provision of internal cooling ducts if required. Thus, with the pumpless steel tank rectifier it does become economic to increase the rating per cylinder and so obtain an increased output per unit floor area. To effect the necessary dissipation of heat from the walls of the vessel, use is made of a system of ducting through which cooling air is forced under pressure of a fan. The power dissipated varies over the active portion of the surface from 2 to 6 watts per square inch of cooling area, and recent improvements have resulted in a more simple, yet equally effective arrangement of air ducting. Because of the absence of heavy metal parts and cooling liquid, the air

cooled rectifier soon reaches its normal working temperature, perfectly reliable starting being obtainable from 3° C. The initial striking of the arc is effected by locally lowering the surface of the mercury with a solenoid operated cup so as to break contact with a fixed ignition electrode.

Rectifiers as shown in a typical cubicle arrangement (fig. 3), have been manufactured in large numbers and various sizes, with and without grid control, for current outputs from 250 to 750 amperes, while outputs of 1,000 amperes have been obtained under test conditions. As an experiment, 20,000 amperes short circuit was applied to one of those units without ill-effects. The fan and the auxiliary ignition constitute the only auxiliary power demand of this type of rectifier, so that its overall efficiency is very high. Most of the pumpless rectifiers are in service at d.c. voltages of about 500 volts, but the units have been proved suitable for operation at 3,000 volts if required. Incidentally, it is possible to obtain an output of 1,500 kW at 1,500 volts using only two cylinders in parallel. The question of still higher working voltages is merely one of lengthening the anode insulators to suit the new conditions.

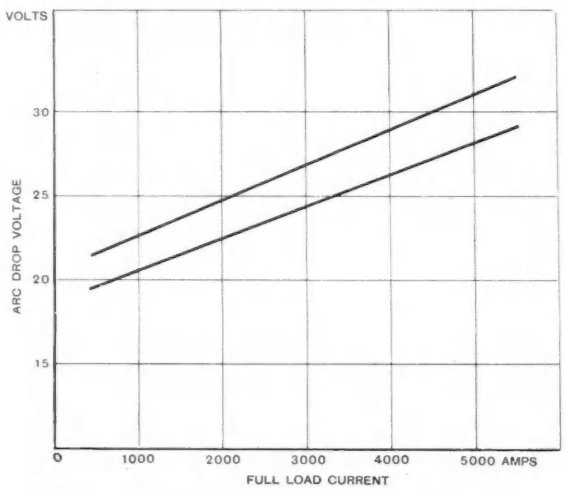


Fig. 4.—Arc drop at full load for different tank sizes. Limits of commercial designs.

Steel Tank Water-cooled Types.[4]

There have been few changes in recent years in connection with the steel tank water cooled rectifiers, but passing reference will be made to some of the leading features.

The whole of the working parts of the rectifier are enclosed within the vacuum vessel, the internally situated anodes being screened from one another by cowls which may be either connected to the tank or insulated therefrom. Improvements and compromise in design and proportioning of the cowls have made possible reliable operation over a wide temperature range down to 5° Centigrade. At the other end of the scale, internal water cooling coils are often used to facilitate the dissipation of heat from the rectifier. Their application is more directed to permitting an increased output from a standard size of tank so as to avoid having to introduce too many tank sizes to cover the usual range of specifications. By way of example, a unit nominally rated at say 1,500 kW can be loaded up to 2,000 kW with this means.

Certain corrosion problems have been encountered in water-cooled rectifiers, and because of "pin-hole" effects and stray currents, the usual anti-corrosive coatings have not been entirely successful. Where conditions are serious, the introduction of metallic salts di-chromates is advocated. These when dissolved in the cooling water induce a passive state at any exposed iron surface, thus limiting leakage currents.

The outstanding differences in construction of the various makes of water cooled rectifier are the methods of sealing off the current leads, the means of anode cooling and the design of the grids. Seals used in connection with mercury arc rectifiers may be divided into two groups, the one group consisting of the seals which also serve as insulators, the other comprising the mechanical seals having a length of porcelain tube for insulating purposes. Examples of the first group are the vitreous enamel and the micalex seals, while the second group includes the mercury seal, the rubber seal and the soldered seal.

Briefly, the vitreous enamel seal (see fig. 1), consists of a number of thin metal cones enamelled all over and fused together to form an insulator of the desired dimensions. Such an arrangement has remarkable electric strength and excellent mechanical properties—the dimensions being governed by flash-over and not puncture consideration. Insulating seals made up in this fashion now range from small 2 cms. diameter seals for grid leading in insulators and vacuum gauge mountings to 50 cms. diameter insulator necessary for insulating the container for the mercury pool cathode. Careful oven temperature control has resulted in the production of very reliable seals of this type. Though the practical limitation is the temperature gradient across the seal itself, it has been found possible to run the rectifier top-plates on which these seals are mounted, at a temperature of 120° Centigrade without damaging the seal. In actual practice the rectifier top-plate temperature rarely comes within 40° of the figure mentioned, so that the factor of safety under working conditions is very high. One of the advantages of this type of seal is that it becomes possible to arrange for air cooling of the anodes and permits the use of a smaller and more robust radiating element on the anode stems. It also enables temperatures of about 80°

4 J. C. READ. "The Application of the Mercury Arc Rectifier to Heavy Engineering." Proc. Rugby Engineering Soc., Vol. XXVIII/2, 1934, p. 1.

Centigrade to be used for the degassing of the rectifier during manufacture.

In the case of the mercury seal, the joint is maintained under a head of mercury and visible means are provided to ensure that the head of mercury is maintained at the proper level. The rubber seal is a simple mechanical arrangement embodying a metal faced rubber gasket, and while this joint can hardly be said to be so permanent as the other two types, experience has proved it to be practicable and free from leakage. These types of seal permit the use of single long porcelain tubes for the anode bushings of higher voltage rectifiers, giving a somewhat cheaper form of bushing than the vitreous enamel type at high voltages. In the case of the mercury and the rubber seals, the operating temperatures should not exceed 80° Centigrade, and the use of water cooling for the anodes is customary with heavy current ratings. The soldered seal is effected by soldering a copper ring directly to the porcelain bush, the said ring being sealed tight to the cover plate. An example of this type is shown in fig. 6.

Various types of cathode insulator are in use, one being the multi-cone vitreous enamel seal and another the porcelain ring type. In the smaller rectifiers using the vitreous enamel seal, no additional external fitting is now required, but with the porcelain rings and the large diameter vitreous enamel types, use is made of a clamping ring with spring loaded bolts to maintain a uniform compressive stress under all conditions of loading and temperature.

Recent anode construction is typified by the almost universal adoption of graphite instead of steel anodes; this is largely due to the good qualities of the graphite at the working temperature of 600° Centigrade, and in particular the low thermal conductivity, the high fusing point, and the absence of sputtering. It is also effective in the construction of high voltage rectifiers. Both the mercury and the oil cooling of the anodes have been abandoned, but air cooling by means of radiating fins clamped to heavy copper anode stems appears to be gaining ground compared with the thermo-syphon water cooled arrangements using large air-cooled water filled radiators.

Mention may be made of the various arrangements of grid adopted for promoting the rapid deionisation of the space in front of the anode needed to impart to the rectifier the high dielectric recovery rate required for polyphase operation. This action of the grids is distinct from the grid control functions which will be discussed later. In the present connection, the graphite grid is being progressively adopted in place of the steel, and high point metal types.

In some cases it is considered that a non-conducting material, such as quartz, forms a superior deionising surface and grids of this material have actually been used. Both the concentric and the louvre types of grids have been found effective in practice. The grid design is largely a problem of providing the optimum conditions in the clearance space between the grid and the anode where the voltage gradients up to 2,000 volts per centimetre have been successfully dealt with. The minimum clearance appears to be limited by auto-electronic emission due to local intensification of the surface field.

As a result of the foregoing developments, it has been found possible to construct thoroughly reliable rectifiers up to 6,000 ampere ratings, and should the demand arise, 10,000 amperes d.c. output could easily be obtained from a single tank. It must be admitted, however, that the enormous current ratings of 16,000 amperes mentioned a few years ago have not proved advisable. The use of a larger tank size involves a longer arc path and also high losses as indicated by the arc drop tank size curve shown in figure 4. On the other hand, it has been found possible to extend the working voltage of rectifiers up to 50 kV, but here the gain in voltage output can only be obtained by drastically derating the current output from a given tank size. Fig 5 shows how the increase in the voltage rating severely limits the current loading.

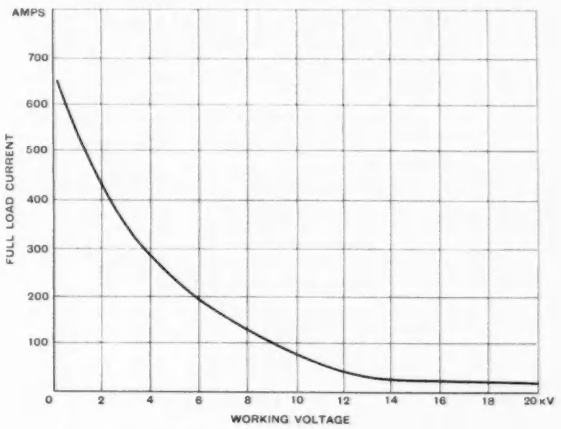


Fig. 5. Influence of working voltage on current output of rectifier.

Whilst dealing with the size of rectifiers, a consideration of the sectionalised type of rectifier used in America may be of interest. The makers claim that the economic balance between efficiency, reliability and cost has an optimum value corresponding to rectifier sizes ranging from 1,250 and 3,000 amperes, as compared with the usual 5,000 amperes for large sized units. The assembly of the cellular units is facilitated by making each section complete in itself, that is with all auxiliaries mounted

on the rectifier, the whole being contained in an earthed cubicle. Larger outputs are obtained by adding further units in parallel so that the voltage drop is always maintained at about 23 volts as compared with a probable 30 volts for a very large unit. The sectional rectifier has made little headway in Europe, due mainly to the different viewpoint and manufacturing tendencies. With the introduction of the air cooled pumpless rectifier, whose outputs per cylinder are rapidly approaching the values suggested in connection with the sectionalised system, the position becomes altered and the sectionalised system might well be applied to give not only increased efficiency, but a considerable saving of weight and space using pumpless steel tank rectifiers.

Igniter Units.

These units, of which the so-called "Ignitron"[5] is the chief example, represent a recent phase in the development of the mercury arc rectifier The polyphase ignitron is made up of an assembly of single phase units each provided with an igniter rod of semi-conducting material such as boron carbide (silicit), inserted permanently in the mercury (see fig. 6). At the ignition instant, the ignition circuit receives a current impulse, and the resulting voltage field, produced by the concentration of the current at the junction of the igniter rod and the surface of the mercury, is sufficiently intense to give rise to a cathode spot which allows the power arc to form. Actually, the time lag on the formation of the main arc is less than 100 microseconds The ignition principle is remarkable in many ways; it is for example still effective at minus 200° Centigrade, though it does not follow that a stable arc is produced at these low temperatures. A further improvement in this direction has been the slotting of the igniter electrodes to give a reduced starting current at a slightly higher voltage. The ignition is timed with the aid of small grid controlled mercury vapour rectifier circuits and these would be conveniently excited from a synchronously driven induction generator The diagram of connections is shown in fig. 7, from which it will be seen the ignition is dependent upon the proper functioning of the continuously running auxiliary valves.

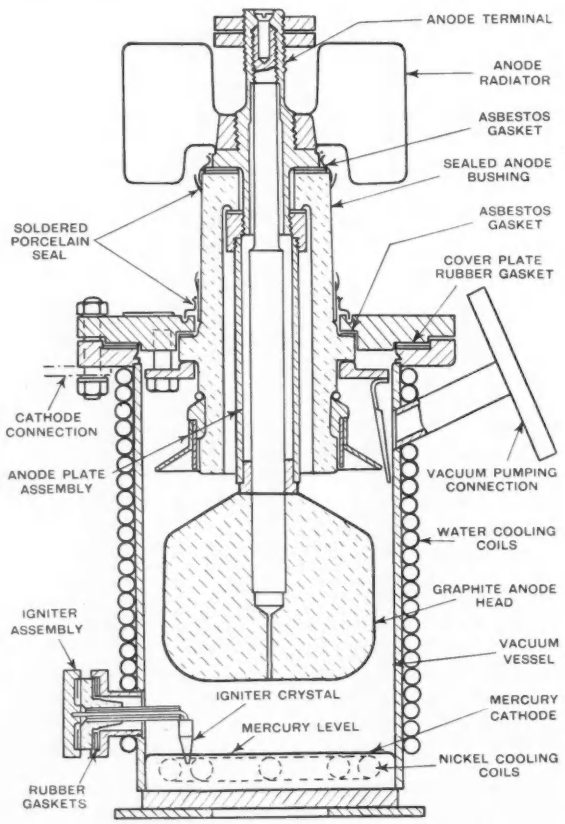


Fig. 6.—Ignitron single-phase rectifier.

Ignitron experimental development has taken two main directions, the first constituting single phase units for half cycle welding, and the second a normal controlled rectifier proposed for industrial purposes. The ignitrons are made both in pumped and sealed off designs; the former are atomic hydrogen welded and bolted together, and the latter are electrically seam welded and sometimes copper brazed. Light internal parts are used to avoid prolonged pumping programmes. The sealed off type has been made in units up to 250 amperes and general use is made of the 75—100 mean ampere sizes, for which the output does not warrant the cost of a pumping system.

Fig. 6 shows the cross sectional view of a rectifier fitted with the usual vacuum pump connections and rated at 250 amperes for electro-chemical service The chief attraction of the welding application is the controlled time intervals through which the current can be allowed to flow. In the case of the half cycle welding units, the problem has been the tendency of the cathode spot to travel outwards in the direction of the wall of the vessel, but this has been overcome by means of a suitably dimensioned cathode Such units have been constructed for 500 volts and with peak current densities up to 500 amperes per square inch The small sealed-off welding ingitrons are made with both glass and with water-cooled metal containers. Hydrogen diffusion has been prevented by using stainless steel, while an iron cobalt nickel alloy (kovar) is used to effect connection to the glass seals. Outputs up to 7,000 amperes peak have been obtained from a group of ignitrons, corresponding to about 100 amperes (mean) per valve.

5 D. PACKHARD and J. HUTCHINGS. "Sealed Off Ignitrons for Welding Control." Elect. Eng., 1937, Vol. 56, p. 37.
J. SLEPIAN. "The Ignitron—A New Mercury Arc Power Converting Device." Electric Journal, 1936, Vol. 33, p. 267.

The use of separate vacuum vessels for each anode cathode pair means that there is an absence of ionised vapour between the electrodes during the reverse half cycle so that a close electrode spacing becomes possible. Advantage can be taken of this fact to produce low voltage polyphase ignitron rectifiers with about 13·5 volts arc drop at 300 volts where shielding can be largely dispensed with. As a result of this, it is possible to apply this type of apparatus economically to a.c. voltages as low as 200 volts. At 600 volts there is need for shielding and the arc becomes increased, while at still higher voltages the arc drop approaches the normal value for a mercury arc rectifier and so far as efficiency at the higher voltages is concerned the difference is practically negligible. Incidentally, ignitron rectifiers have been operated at 16 kV with the current reduced to 5 amperes.[6]

Rectifier Auxiliaries.

It is not possible in this paper to deal at length with the wide subject of rectifier auxiliaries, but some notes will be given on a few outstanding features thereof.

Ignition.

A.c. and d.c. ignition systems are both available, the tendency being to standardise whichever of the two systems is already in use on a given scheme. The d.c. method has some practical advantages inasmuch as the ignition gear is not constrained to open in the correct half of the working cycle before proper ignition can result.

Vacuum Pumping System.

Vacuum pumping practice appears to be more or less standardised, although the various makes of preliminary vacuum diffusion pumps differ slightly in construction. Under ideal conditions it is possible to produce pressures as low as 0·1 mm with the rough vacuum pump, but the mercury vapour diffusion pump is still necessary to reduce the foreign gas pressure of one micron at which the rectifiers usually operate. The actual mercury vapour pressure may, of course, be higher. Two forms of heater are available for diffusion pumps, the a.c. single turn transformer type and the resistance heater. The former is preferred on the grounds of longer life, but the latter can be used with alternating or direct current, and is more convenient to demount, if necessary.

The control and measurement of vacuum is essential for the successful working of the water cooled rectifier. Two types of vacuum gauges are available, namely the McLeod compression gauge and the Pirani hot wire equipment. The Pirani gauge, based upon the Wheatstone Bridge method of measurement, indicates the pressure by recording the thermal conductivity of the residual gases. Both types of gauge have been recently improved in their construction, the McLeod gauge being now available in a more compact form, while the Pirani gauge has had improved mounting and the use of the vitreous enamel seal in its construction. Incidentally, the latter gauge is also employed to operate the vacuum relays associated with the water cooled rectifier.

Cooling.

The cooling systems used in connection with the water cooled rectifier have remained substantially unchanged, the water being circulated through the rectifier water spaces to the heat exchanger by means of a centrifugal pump. Thermostatic valves, operating on the bi-metal strip principle, provide a convenient means of regulating the flow of cooling liquid.

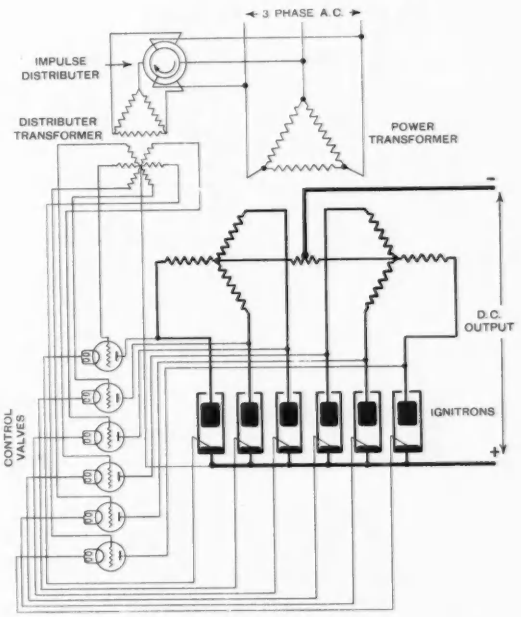


Fig. 7.—Main and auxiliary circuits for ignitron rectifier.

Thermosyphon cooling, a normal mains water supply or a small circulating system is employed for the diffusion pump, and the water cooled valve connecting the rectifier to the vacuum pumping system. Alternatively, the valve may now be air cooled if desired.

4. EXPERIMENTAL TYPES.

While they have not reached the stage when general application can be made, the non-vacuum rectifiers have made considerable progress in recent

6 C. B. Foos and W. Latteman, H.V. Mercury Pool Type Rectifiers. Am. Inst. Radio Engineers. 1936, Vol. 24, p. 977.

years. Although much development still remains to be done, some notes on these types may be of interest.

Mercury Jet Types.[7]

Development work continues to be carried out on the mercury jet types of rectifier, and a new testing laboratory, inaugurated in 1937, for this purpose with testing facilities up to 1,000 kVA has been erected in Denmark.

Three types of mercury jet rectifier have been proposed—the jet wave rectifier, the jet disc type and the truncated jet type. Most of the development work has been carried out on the jet wave type, but the other two types are of considerable experimental interest. The jet wave type, of which several descriptions have already been published, makes use of the synchronous lateral deflection of a mercury jet supplied with a.c. and subjected to a steady magnetic field. The free end of the jet is made to traverse current collecting combs, thereby producing the synchronous switching action necessary for rectification. For polyphase working three single phase units can be arranged with their jets in the proper phase relationship to produce correct phase commutation. Recent developments have been improvements in the auxiliary electrode systems which enable the current contact to be made with the minimum of distortion of the moving jet These modifications have resulted in a raising of the possible current output from the jet to over 1,000 amperes. A 300 kW, 3,000 ampere rectifier having three single jet commutators is under investigation, and the output of each of these commutators has been recently increased to 125 kW. The general tendency is to reduce the number of jets for a given power output; at the same time the voltage on each jet can now be raised to 1,000 volts. The 200 kW jet wave rectifier has already been successfully demonstrated on 500 volt tramway systems, and a 1,000—2,000 kW traction rectifier is under consideration.

An important feature of the jet wave rectifier is its efficiency at low voltages. Above the 500 volt range there is little to choose between this and the other rectifiers, but in the range from 50 to 200 volts its overall efficiency remains at the comparatively high values of 90—94 per cent. Tests have shown the rectifier to have a good overload capacity and to be capable of withstanding short circuits, while more recently the possibilities of inverted operation of the jet wave rectifier have been demonstrated.[8]

7 J. HARTMANN. "The Jet Wave Rectifier." Journal I.E.E., 1930, Vol. 68, p. 945.

"The Jet Wave Commutator as means for the Production and Conversion of Heavy Direct Current, Large Powers and High Voltage." Archiv fur Elektrotechnick, 1935, Vol. 29, p. 855.

J. HARTMANN. "The Plate Jet." (G. E. Gad, Copenhagen, 1935).

8 W. E. FRENCH. "High Voltage D.C. Transmission," Electrical Review, 1936, Vol. 118, p. 47.

Gas-Cooled Arc Type.[9]

The gas-cooled arc types have passed through a number of experimental stages during the past few years and have now regained much of their original simplicity, as will be seen in figure 8. The chief features of these valves at the present time are the straight-through axial air flow and auxiliary arc ignition. The power arc burns between two main electrodes and they are provided with screen electrodes to decrease the intensity of the electrostatic field of the reverse voltage in the heated region of the arc foot point. One of these screen electrodes is insulated and serves also as an ignition electrode. An ignition voltage of about 5 kV is sufficient to break down the gap between the ignition electrode and its main electrode, and thus, the current for the auxiliary arc is now obtained direct from the power transformer. The auxiliary arc is produced at one electrode system, carried across to the other electrodes by the air flow and initiates the power arc between the two main electrodes. The power arc in turn commutates the auxiliary arc, thereby restoring the small insulating gap between the main and the ignition electrodes. The auxiliary arc may be either at the anodic or at the cathodic electrode. Thus the reversibility of the power flow is not impaired, and

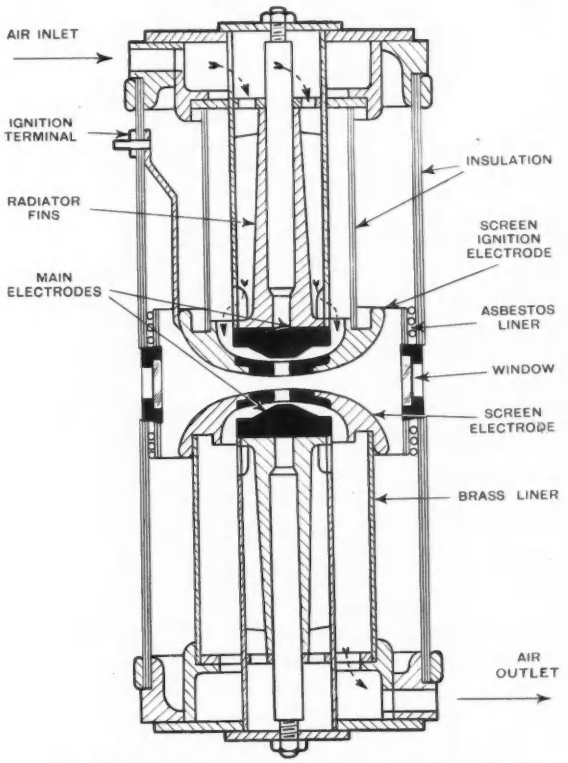


Fig. 8.—Sectional elevation of Marx-type valve.

9 ERWIN MARX. "Arc Converters." Julius Springer, Berlin, 1932.
W. G. THOMPSON. "The Application of a Gas-cooled Arc to Current Conversion." Journal I.E.E., 1934, Vol. 75, p. 603.

the polarity of the valve will depend upon the half cycle in which ignition takes place.

The quenching of the power arc occurs at the current zero under the combined cooling and scavenging action of the air flow. The rate of recovery of the electric strength of the valve under heavy current has been measured by high speed oscillograph methods and appears to meet all practical requirements. The valves have been operated successfully at heavy currents up to 2,000 amperes (peak), and at moderate voltages, and at very high voltages, *i.e.*, 300 kV, and light currents. Effective use of circulating air under a pressure of about 10 atmospheres enabled high reverse voltages to be withstood at practicable electrode spacings. The arc voltage load current curve has a drooping characteristic falling to about 70 to 100 volts at currents of about 100 amps. d.c. output. This is somewhat high, but the arc voltage represents a negligible loss with the valve operating at several kV. The problem of electrode erosion is still under investigation. Considerable improvements have been made by the use of extended electrodes and electrode lives of some thousand hours can be obtained. The momentary overload capacity is usually ten or more times the normal full load working current. The operation of the valve can be stopped immediately by cutting off the ignition, while by adjusting the ignition the power output of the valve can be limited as desired. The valves have been operated in three phase and six phase circuits as a rectifier, and also as an inverter. In both cases the operation has been satisfactory, and so long as the conditions necessary for phase commutation are maintained there is no difficulty. With electrode separations corresponding to a nominal breakdown voltage of 30 kV peak, these valves have been operated satisfactorily at atmospheric pressure with reverse voltages of over 20 kV peak in a three phase circuit. The factor of safety would be obtained by raising the air pressure rather than by increasing the electrode separation. The general tendency for development at the moment is for high voltages and moderate currents, but the application of these valves is largely a question of suitable opportunity arising.

Hydrionic Rectifiers.[10]

These rectifiers, of which many widely different experimental forms have been produced, appear to be most suitable for operation at moderately low voltages. The arrangement in every case is such that during the conducting period the current is carried by an electrolyte. In order to deal successfully with the leakage on wetted insulating surfaces, the more practicable designs arrange the electrolyte in the form of high speed jets. One form of this rectifier makes use of a synchronously rotating arm cutting into an equally spaced group of jets that correspond to the number of phases on the transformer. The voltage drop of such a rectifier is dependent upon the nature of the electrolyte used and the effective design of the nozzle in the moving part which completes the circuit through the jets. By careful design and provision of large electrode areas and small clearances, voltage drops below 10 volts with currents of 500 amps. have been measured.

There still remains a number of problems to be solved in connection with these rectifiers, notably the handling of the alkaline caustic electrolytes used and the electrolytic gases evolved. The temperature coefficient of resistance of the electrolytes also requires careful study. An interesting phenomen in this type of rectifier is the sparkless break at commutation which may be ascribed partly to the difficulty of cathode spot formation and partly to the high resistance of the liquid path at the point of the electrode separation.

10 Brit. Pat. Nos. 447095, 453080, Nov. 1934.

(*To be continued*).

The Unit Sectional Drive of a Large Paper Machine.

With Special Reference to the Recent Electrification of a Paper Making Machine at the Mills of the Imperial Paper Mills Limited.

By W. J. MASON, A.I.E.E.
G.E.C. Engineering Dept., London.

In an article entitled "The Electrical Control of Paper Making Machinery" which appeared in the G.E.C. Journal, November, 1937, the author discussed the problems involved in the driving and control of paper making machinery and described a system introduced by the G.E.C.

In the accompanying article a description is given of an interesting conversion to this system of a large steam-engine driven paper making machine at The Imperial Paper Mills Ltd., Gravesend. Its successful operation has resulted in a further contract for the complete sectional drive of a new and larger machine for the same Company.

AS a result of extensive research work during recent years paper makers now possess a greater understanding of the chemical and physical changes that occur in the treatment of the fibres, and one result of this knowledge is that satisfactory formation of the sheet on the wire can be obtained at speeds that were impossible ten years ago. This applies throughout the industry from fine paper making to the large wide machines engaged on the mass production of newsprint, but it is on the latter machines that the most striking and spectacular developments have occurred. The following description tells how an existing newsprint machine was modernised to enable full advantage to be taken of the progress made since it was originally installed. It also illustrates the special advantages of the unit electric drive, which was described briefly in a previous article[1] and will serve to emphasise the reasons that are causing unit drives to supersede the older belt or rope drives that have been used universally since the first paper machine was set to work at Dartford about 1802.

One of the largest paper mills in the country is owned by The Imperial Paper Mills, Ltd., of Gravesend, Kent, where thirteen paper machines with an annual production of 160,000 tons of fine printings and newsprint are now in operation. An aerial view of the mill is shown in fig. 1. The Imperial Paper Mills, Ltd., decided at the end of 1936 to reconstruct one of their existing paper machines and make it suitable for running at twice the speed. The machine concerned had a width of

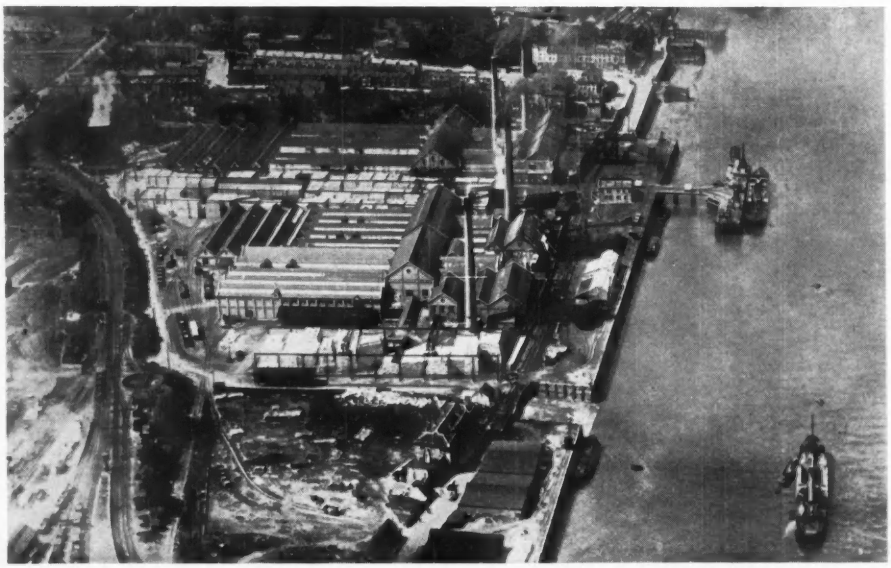


Fig. 1.—Aerial view of The Imperial Paper Mills, Ltd., Gravesend.

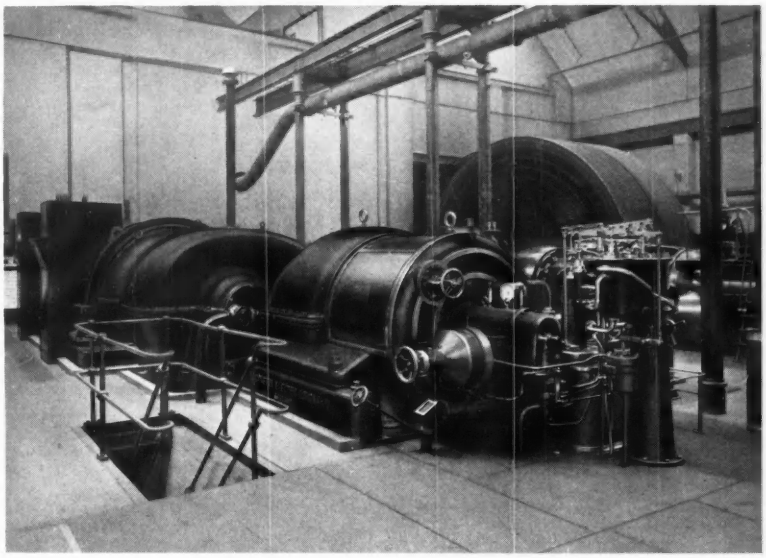


Fig. 2.—3,750 kW geared pass-out turbo-generator, supplying steam to the dryers of the paper machine and power to the booster and crawling sets.

wire of 157ins. with a trim of 144ins. and was originally driven by a cone-pulley belt from a back pressure steam engine, the exhaust steam being used in the paper drying cylinders ; it was set to work in 1923 for a speed range of 400—700 ft. per minute.

It was specified that after reconstruction the machine was to be suitable for a speed range of 350—1,100 ft. per minute, which was considered an economical range of speed for meeting the requirements of fine print or high class news manufacture ; a crawling speed of 70ft. per minute was also required.

It was decided to install an electric drive of the "Witton" unit sectional type. In order to obtain the necessary drying steam the high pressure blading of an existing 3,750 kW 3,600 r.p.m. G.E.C. Fraser & Chalmers passout turbine, installed in 1929, was reconstructed to give an increased quantity of pass-out steam. This turbine (fig. 2) operates with steam at a pressure of 165 lb. per sq. in. and a temperature of 520° F. at the stop valve and originally passed out 20,000 lb. of steam per hour at a pressure of 10 lb. per sq. in.; since reconstruction, up to 50,000 lb. of steam per hour can be extracted at pressures from 15 to 25 lbs. per sq. in. It drives two 460 volt D.C. generators in tandem, supplying current to the paper machine. It may be noted that a similar turbo set of 5,000 kW capacity is now under construction for this mill.

Since the new drive was set to work it has fulfilled the specified requirements in every way. It enabled the paper machine to reach the maximum speed within a few weeks of starting up, and runs of over 15 or 20 hours without a break are quite common.

"WITTON" UNIT SECTIONAL DRIVE.

The "Witton" unit sectional electric drive installed consists of six D.C. sectional driving motors, each having its own control panel and automatic draw-regulating mechanism. A positive and negative booster set is provided to supply power for normal running, a low voltage motor-generator set for starting and crawling purposes, and a master frequency set for the draw control and speed stabilizing gear.

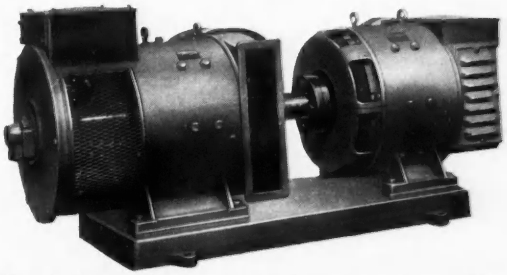


Fig. 4.—Low voltage motor generator set supplying power for starting and crawling.

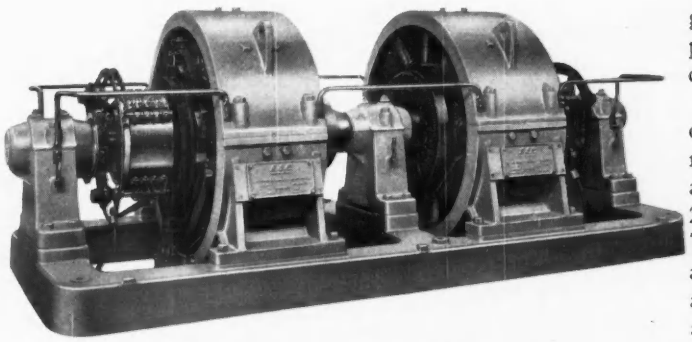


Fig. 3.—Booster motor generator set giving a variable voltage supply to the paper machine.

The first two motor-generator sets are driven by D.C. motors fed from the 460-volt mill supply. The booster set (fig. 3) runs at 750 r.p.m. and gives a 140-volt boosting or 260-volt bucking supply to the section motors. The crawling set (fig. 4) runs at 1,000 r.p.m. and gives a 50-volt D.C. supply that allows any section of the paper machine to be run at low speed when required.

The master frequency set, which can be seen on the right hand side of fig. 15, consists

is of the positive type and is unaffected by voltage or temperature changes.

The cone pulley drive enables the speed of any section motor to be varied up or down to give greater or less draw. If the draw is to be increased, the draw control switch is operated, moving the cone pulley belt (by means of the guide pulleys and their operating mechanism) towards the smaller end of the motor pulley and at the same time towards the larger end of the section alternator pulley. This causes the section alternator to run at a lower speed, but immediately the speed starts to fall the reduced frequency from the section alternator causes the draw regulator to function and weaken the field of the driving motor, which accelerates to the desired speed.

The draw control mechanism gives a draw adjustment of plus or minus $12\frac{1}{2}$ per cent over the draw allowed in the reduction gears. This allows the full life of the rubber covered rolls to be obtained and still leaves sufficient adjustment in the draw to deal with normal paper making; there is therefore no need to change the cone pulleys.

AUTOMATIC DRAW REGULATION.

For maintaining constant draw between sections, each section of the paper machine is provided with an automatic draw regulator working on the principle of an electrical differential; the six draw regulators can be seen in their glass-fronted cases on the lower panels of the switchboard in fig. 15.

Each regulator consists of a stator and a rotor, which operates a D.C. rheostat connected in the field system of the section motor concerned. The stators are connected in parallel and supplied from the master frequency set, and each rotor is supplied from the appropriate section alternator. Thus the stators are supplied at a frequency proportional to the drive voltage and the rotors at a frequency proportional to the angular velocity of the paper machine rolls. The draw regulators are designed so that these two factors are matched against each other, and the speeds of the driving motors are automatically regulated to maintain the desired relation between them.

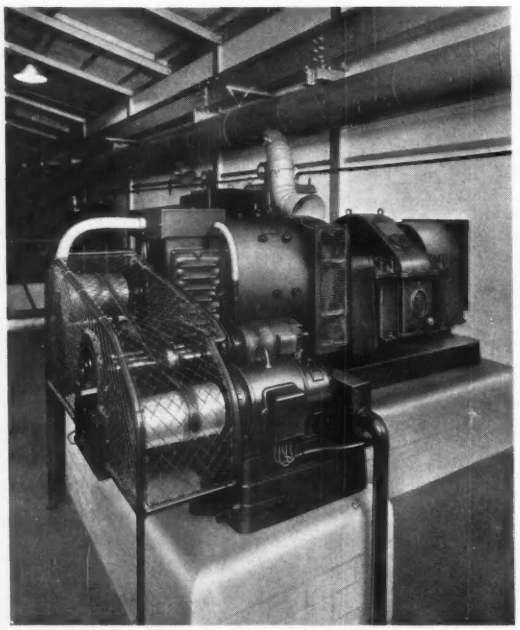


Fig. 10.—The driving unit of the second press with the draw control mechanism in the foreground.

Fig. 11.—Section controller with draw control switch and draw indicator.

DRAW REGULATORS.

The details of the construction of the draw regulators are of considerable interest. Each stator and rotor is liberally designed for the small output required, being capable of developing from 60 to 100 times the torque necessary to move the rheostat sectors. The torque developed follows closely a sine curve, so that the smallest phase displacement between stator and rotor produces a strong torque under all conditions and there is no lost motion in the operation of the regulator; another important point is that the torque is constant throughout the whole speed range.

Special care has been taken in the design to eliminate all sliding friction; stator and rotor are enclosed in a dust-proof case, ball-bearings are used, and all contacts are of the rolling type. Owing to the strong torque exerted and the small mass and frictionless operation of the regulator parts, it reacts instantaneously to the smallest change in the angular velocity of the paper rolls compared with the uniform velocity given by the master frequency set. In order to prevent hunting of the regulator due to resonance with the paper machine sections, a damping

device is provided in the form of a disc rotating between the poles of permanent magnets; the relative position of the magnets is adjustable over a wide range to suit the varying characteristics of the

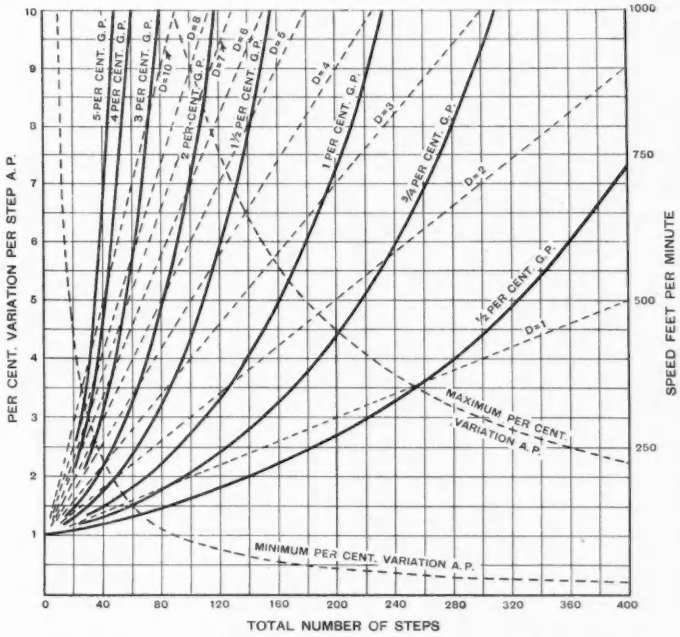


Fig. 12.—Comparison between arithmetical and geometrical grading of speed controller steps.

different sections. The rheostat sectors, the angular movement of which is a magnified reflection of the variation on the roll of the paper machine, roll in a vee-groove in the contacts, which are constructed similarly to a commutator, giving the minimum distance between contacts; this ensures that both the degree to which the angular velocity of the rolls can deviate from that of the master frequency set and the amount of sector movement necessary to give the required correction on the section driving motors are as low as possible.

The draw regulator is arranged to act as a full field relay during the starting and accelerating periods, the rheostat sectors returning automatically to the full field position when the section motor stops; when up to speed a synchronizing relay is energised, allowing the sectors to travel slowly into the working position and to take over the control without swinging or hunting.

The sectors and operating mechanism and also the synchronizing relay are mounted on the front of the regulator and are enclosed in a dust-proof cover with a glass front allowing their operation to be observed. A positioning rheostat also is built into the case and is operated by a knurled knob on the outside, allowing the sectors to be set to the best working position without opening the hinged front of the case. The resistances are mounted at the back of the regulator and enclosed in a ventilated sheet metal cover.

The whole regulator forms a complete self-contained unit that can be mounted in any desired position.

ADVANTAGES OF INDEPENDENT DRAW CONTROL.

It will be seen that an essential feature of the "Witton" unit sectional drive is that all the sections of the paper machine are controlled by an independent master frequency set, in contrast with other systems in which the dryer section is used as the master control unit. This arrangement, which is the result of thorough investigation and discussion with paper makers and mill engineers, has the advantage of giving greater flexibility and complete and continuous control of the whole drive, every section being under constant supervision.

In fast-running machines, breaks are liable to occur in the dryers, which must be shut down to clear the "broke," the normal procedure being to break down the sheet at the couch section, leaving the stuff on the wire. This means that with the dryers as the master control the couch section is only under partial control, and while the dryers are being brought up to speed again the couch is subjected to all the supply variations and the voltage drops in the converter set caused by the dryer starting and accelerating peaks. These variations affect the speed of the couch drive, causing thickening of the sheet (since the quantity of stock is constant), which in turn increases the load on the couch; the latter slows down still further, so that the effect is cumulative and may result in the wire

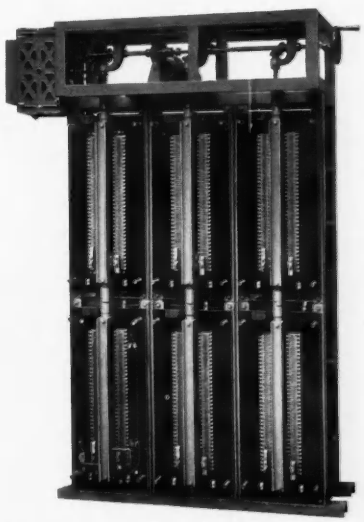


Fig. 13.—Motor-operated potentiometer controller for machine speed control.

skidding or slipping on the drive roll. It is then necessary to shut down and start afresh, which naturally reduces the output of the machine. Again, with control from the dryers any small cyclic irregularities set up by the dryer gears not running dead true will be transmitted to all other sections of the machine.

With the type of draw regulator employed on the sectional unit drive described all these disadvantages are eliminated, the productive capacity of the machine is increased, and steadier running is maintained. The operating results show that the slight extra cost involved is fully justified by the completeness of the control afforded.

MACHINE SPEED CONTROL.

For every paper machine there is a definite maximum quantity of stock that can be handled, giving a definite output in unit time. This is determined by the thickest sheet that can be formed on the wire and the drying capacity of the cylinders. Hence the weight of paper produced can be varied either by altering the amount of stock flowing on to the wire or by altering the speed of the machine as a whole. With the first method, assuming that the machine is working to its full capacity (*i.e.*, the maximum amount of stock is passing on to the wire), the weight of paper can only be varied by reducing the amount of stock handled, which of course reduces the capacity of the machine. With the second method, however, the weight of paper can either be increased or decreased, and at the same time the productive capacity can be maintained at its maximum value. Hence, in order to obtain the greatest possible output from a paper machine, the weight of paper should be adjusted by the method of speed changes.

With the usual specification, paper is rejected if the weight is more than 2½ per cent above or is less than the specified figure, and to adjust the weight without exceeding these tolerances small increments of speed are essential. The method of grading the steps on the main speed controller has been much debated among paper makers and paper mill engineers. They can be graded either to give equal percentage increases of speed (geometrical progression) or to give equal increments of speed over the whole range (arithmetical progression). To keep the weight of paper between the limits mentioned above, the speed steps at lowest speed must not exceed 1½ per cent with arithmetical progression or 1 per cent with geometrical progression.

The two systems can be expressed by the simple formulae:

$$n = \frac{t-b}{d} + 1$$ (controllers graded arithmetically, *i.e.*, equal increments).

and $$\frac{t}{b} = r^{n-1}$$ (controllers graded geometrically, *i.e.*, equal percentage increments)

where n = number of steps,
t = top speed,
b = bottom speed,
d = difference between steps,
and r = ratio of adjacent steps.

A graphical comparison is given in fig. 12 for a speed range of 10 : 1. It will be seen that geometrical progression enables the smallest number of steps to be employed, but at high speeds the difference between steps is too great and the control too coarse for practical use. For this reason the majority of users prefer their controllers to be graded arithmetically.

On the machine under discussion the speed of the drive as a whole is controlled by means of a motor-operated potentiometer controller which is connected in the field of the motor of the booster set, thus varying the voltage of supply to the section motors. The controller is provided with a large number of steps graded to give equal increments of speed over the whole range; a typical controller is shown in fig. 13. For the whole speed range the increments are 5ft. per step, which corresponds to speed increases of 1·4 per cent at bottom speed and 0·45 per cent at top speed.

AUTOMATIC SPEED REGULATION.

Accurate maintenance of the desired speed independent of external circumstances is desirable for various reasons, some of which were mentioned in the previous article. A self-contained speed regulator has accordingly been developed[2] which meets all the requirements of paper machine drives, giving a speed regulation of plus or minus ¼ per cent over the whole speed range.

The principle employed is the balancing of a selected drive voltage against a constant voltage produced by a "lamp bridge."

The drive voltage is obtained from the third machine in the master frequency set, which supplies a rectifier whose output is passed to the speed regulator through a rheostat. This rheostat is ganged to the main speed controller, so that when the controller is operated to raise or lower the speed the rheostat is operated also, reducing or increasing the rectified voltage.

The lamp bridge is a device that has the property of giving an absolutely constant voltage independent of wide variations in the supply; in this case, the output voltage does not vary more than 0·05 per cent with a supply voltage ranging from 380 to 500.

The drive voltage and the constant voltage are connected in opposition through a very sensitive type of polarized relay. Any difference in the

2 G.E.C. Prov. Pat. Application No. 6898/37.

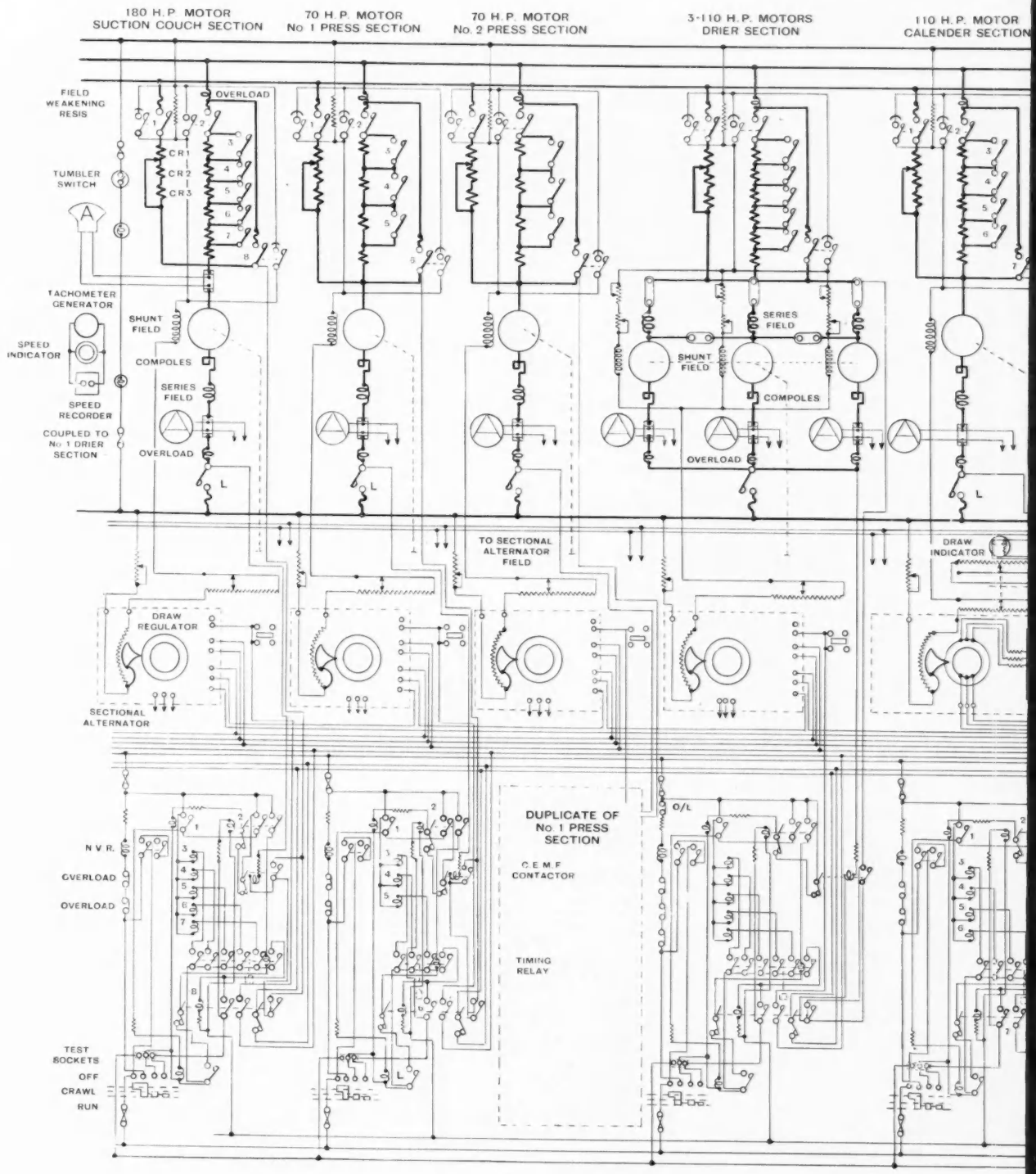
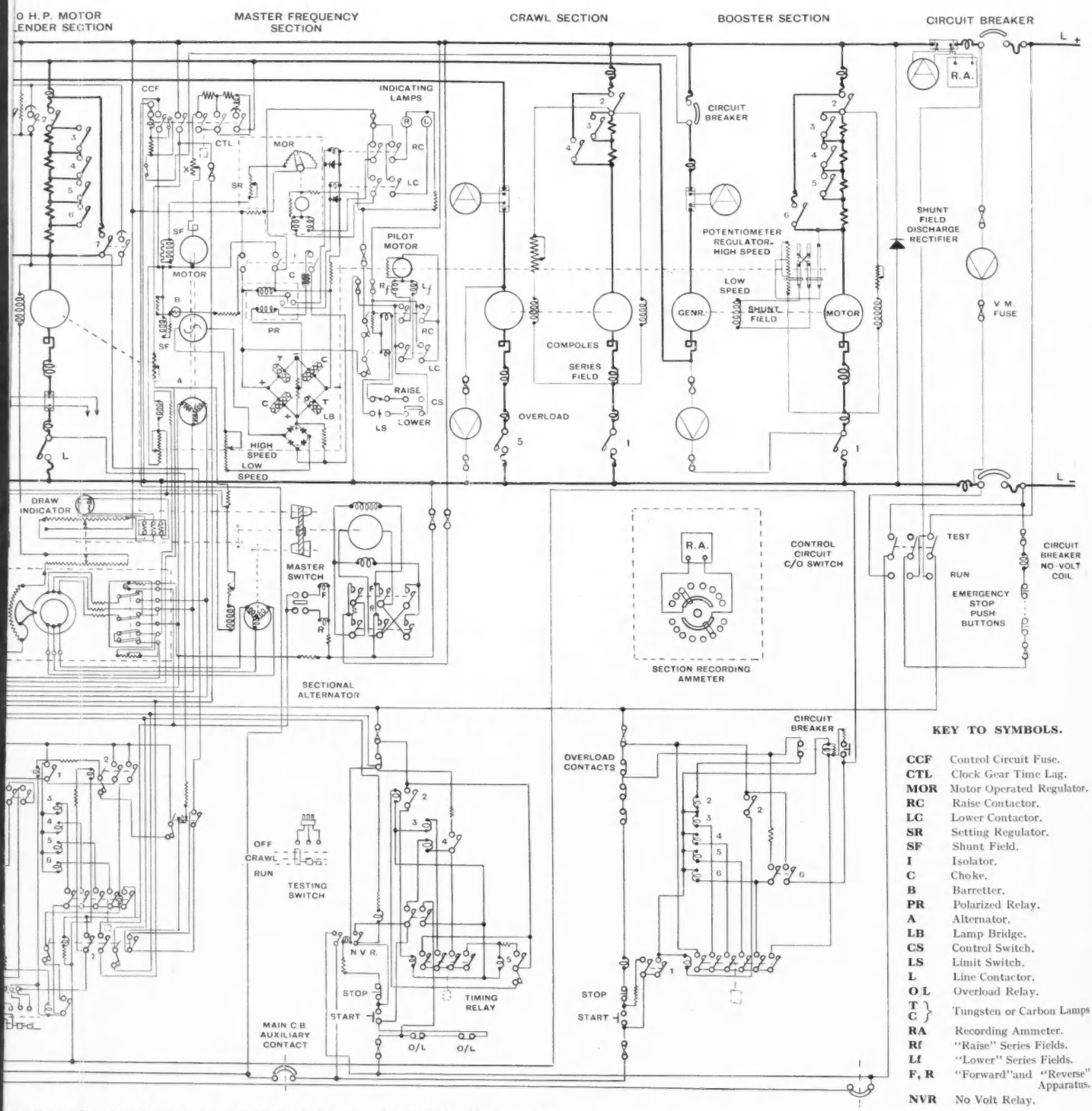


Fig. 14.—Diagram of connections for "Witton" sectiona



KEY TO SYMBOLS.

CCF	Control Circuit Fuse.
CTL	Clock Gear Time Lag.
MOR	Motor Operated Regulator.
RC	Raise Contactor.
LC	Lower Contactor.
SR	Setting Regulator.
SF	Shunt Field.
I	Isolator.
C	Choke.
B	Barretter.
PR	Polarized Relay.
A	Alternator.
LB	Lamp Bridge.
CS	Control Switch.
LS	Limit Switch.
L	Line Contactor.
O/L	Overload Relay.
T, C	Tungsten or Carbon Lamps
RA	Recording Ammeter.
Rf	"Raise" Series Fields.
Lf	"Lower" Series Fields.
F, R	"Forward" and "Reverse" Apparatus.
NVR	No Volt Relay.

tton" sectional unit drive at the Imperial Paper Mills Ltd., Gravesend.

relation between them operates this relay, making contact with further relays that control a small motor-driven regulator; this regulator is connected in the field of the motor that drives the master frequency set, and thus varies the speed of the latter to compensate for variations in the speed of the paper machine. Means are provided to compensate for the effect of temperature changes in the circuits.

It will be seen that the speed regulator described takes care of variations in the supply voltage, the load, and the temperature of the surrounding air. It is entirely self-contained and is independent of any external supply. It has been proved capable in practice of holding the machine speed constant within $\frac{1}{4}$ per cent under all conditions from the initial starting up to the week-end shut-down. The paper can thus be made to a much closer specification, and the weight can be maintained well within the usual tolerances.

GENERAL ARRANGEMENT OF SWITCH AND CONTROL GEAR.

A schematic diagram of connections for a typical "Witton" sectional unit drive was given in the previous article, and the detailed connections for the Imperial Paper Mills installation now under consideration are shown in fig. 14. The main incoming supply is taken at 460 volts D.C. through a line contact circuit breaker to the booster and the crawling sets. The

Fig. 15.—Main switchboard showing a draw regulator mounted on the first panel, and the master frequency set on the right hand side.

former feeds the section motor busbars through an electrically-operated line contact breaker, and the latter supplies the crawling busbar through an electrically-operated contactor. The contactor starters for the booster and the crawling sets are suitably interlocked with the remainder of the switchgear, and the full complement of instruments provided includes for the booster set a recording ammeter for the total power and a recording ammeter and

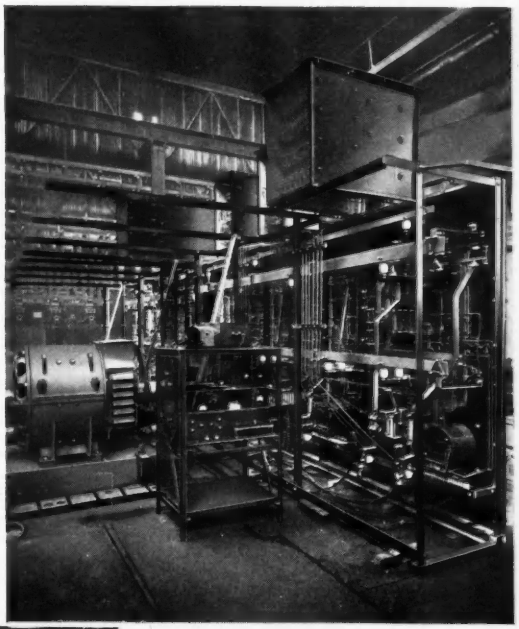


Fig. 16.—Cathode ray oscillograph arranged for speed constancy test at the Witton Engineering Works.

selector switch giving the power used by any one section.

The main switchboard, illustrated in fig. 15 (taken on site), and fig. 17 (taken at Witton Engineering Works during test) comprises fourteen panels as follows (from left to right):

1 and 2	Couch section.
3 and 4	First press section.
5 and 6	Second press section.
7 and 8	Dryer section.
9 and 10	Calender section.
11	Speed regulation equipment.
12	Crawling set starter and output panel.
13	Booster set output panel.
14	Main incoming and booster starter panel.

The starting resistances are mounted on top of the panels, and the whole board is provided with gates and screens to comply with Home Office Regulations. A separate cubicle at the rear of the switchboard

houses the main speed controller for the booster set and the lamp bridge and polarized relay for the speed regulator.

The whole of the switchgear is of the heavy steelworks pattern, giving maximum reliability. It is of the double pole type and full protection is provided; this includes no-volt protection to ensure that in the event of any section of the paper machine being shut down (either by the emergency stop button or by an overload or a supply failure), the section controller must be brought to the "off" position before the section motor can be re-started. Interlocks ensure that none of the section panels can be operated until the booster and crawling sets are running.

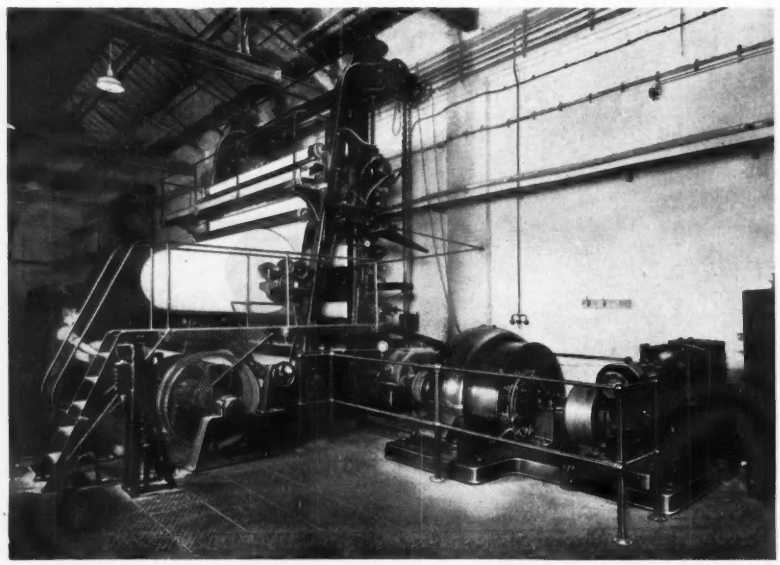


Fig. 17.—Super calender driven by a 285 h.p. variable speed direct-current motor.

A large-scale ammeter for the couch section is mounted at the back of the machine on the couch section instrument panel. A speed indicator mounted on the same panel shows the speed of the whole paper machine in feet per minute and is connected in parallel with a chart-recording speed indicator on one of the dryer panels of the main switchboard.

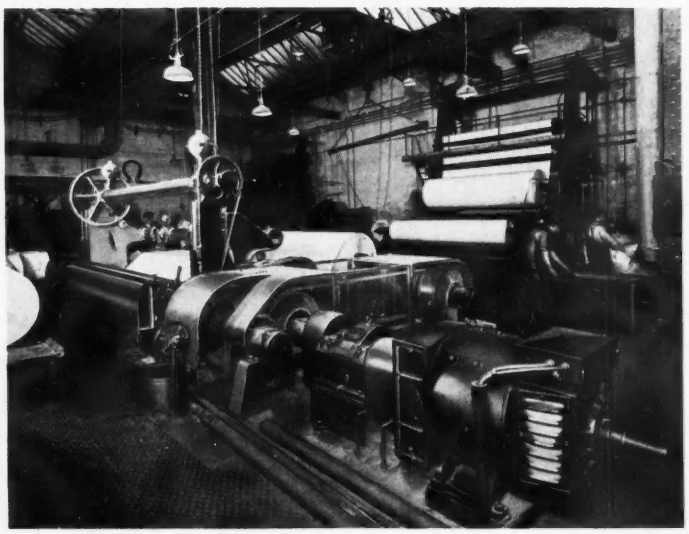


Fig. 18.—Variable speed direct current winder drive, with the super calender in the background.

STARTING UP.

When starting up the machine, the crawling set must be started by hand from its own push-button, but thereafter it is automatically started and stopped as required by the section motors. For instance, as soon as all the section motors are running, the crawling set is automatically shut down; if, however, one section of the machine is stopped the crawling set starts up so as to be ready for re-starting the stationary section. Since operation of the crawling set is normally required for only about 1 per cent of the time that the machine is running, this automatic control system effects considerable economies by eliminating the no-load losses (which would otherwise be almost continuous) and reducing wear and tear. Nevertheless the crawling set is immediately available for use if required.

TESTING CONTROLLER.

For test purposes and week-end maintenance work a separate testing controller is mounted on the wall near the main switchboard and provided

with a flexible trailing cable and plug, enabling any panel to be operated without running the machine section; the test sockets can be seen in fig. 15. Testing current is only available when the main circuit breaker is open, so that it is impossible to operate the section motor if the test switch is inadvertently left plugged into the panel.

Any section of the machine can be turned during the week-end by means of the crawling set, the power required being within the capacity of the usual week-end supply, and it is unnecessary to start up the main booster set for this purpose.

AUXILIARY DRIVES.

In addition to the "Witton" sectional unit drive motors have been installed for driving pumps at the wet end of the paper machine (seen in the foreground of fig. 8), a 285 h.p. super-calender drive with a speed range of 35—800—1,600 ft. per min. (fig. 17), and a winder drive (fig. 18).

The scheme for electrifying the mill also included the conversion of a battery of four super calenders from mechanical drive. For this purpose four 120 h.p. motors with Ward-Leonard sets and automatic control gear were supplied, giving a speed range of 35—100—600 ft. per min. The general view given in fig. 19 shows one of the main motors with the Ward-Leonard set and switchgear in the rear; the driving units were designed to fit the existing foundations, and the change over was carried out during the week-end shut-down, avoiding any loss of production.

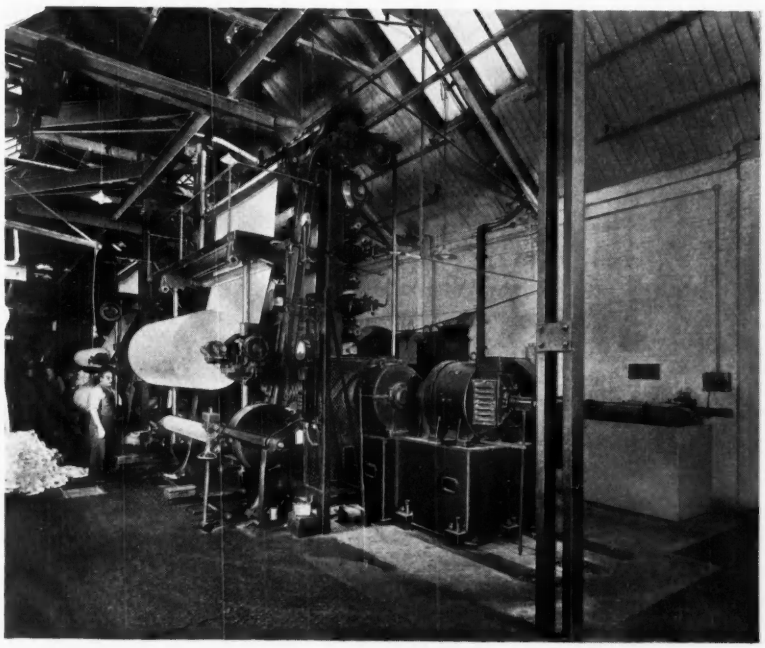


Fig. 19.—Battery of four super calenders converted from mechanical to electrical drive.

In conclusion, acknowledgments should be made to The Imperial Paper Mills, Ltd., for permission to publish this description and the accompanying illustrations.

The Installation of Electrical Apparatus in Hazardous Situations.

By S. W. RICHARDS, M.I.Min.E.
G.E.C. Mines Dept., London.

HISTORY OF FLAMEPROOF PROTECTION.

THE adoption of apparatus to guard against explosive gas can very well be dated back to 1816, when Sir Humphrey Davy designed the miner's lamp. This was an oil lamp in which the flame was surrounded by a metallic gauze, the protection being due to the fact that radiation or conduction of heat from the gauze shield reduced the temperature of any heated gas passing through the gauze to a point at which it would not ignite the gas outside the shield. In effect, therefore, the effect of an ignition is localised within the gauze and prevented from getting outside. The use of such apparatus was confined to coal mining, and in some instances to explosives manufacture. When electricity became adopted as an illuminant in such situations, the main endeavour in design was to prevent the outside atmosphere from getting to the bulb by the use of protective glasses and rubber gaskets or other compressible materials, the aim being to design a gas-proof fitting. After some experience, this was proved to be impracticable. As the heat of the lamp causes a considerable expansion of the air inside the globe, followed by a corresponding contraction when the current is switched off, no gasket or other sealing medium is sufficiently effective to prevent the surrounding atmosphere from being drawn in. There could thus be no claim for a resistance to an internal explosion.

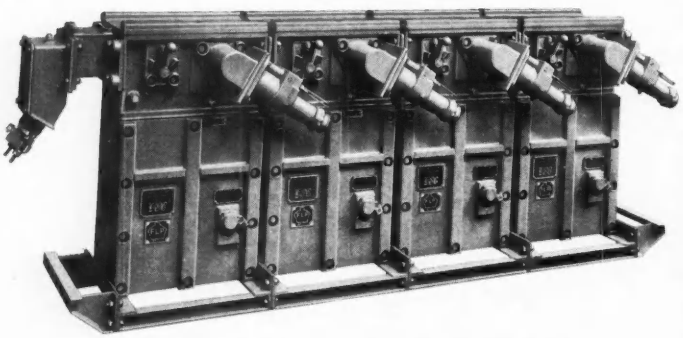


Fig. 1.—Flameproof automatic gate-end panels for controlling coal cutters, conveyers, etc.

The next step brought forward two schools of thought on the subject. One suggested a design of apparatus wherein provision was incorporated to relieve temporarily any pressure which might be developed by an internal explosion—this took various forms, which will be referred to later. The other school suggested designing apparatus which would be strong enough to resist any internal explosion without injury, with means to prevent the flame, consequent upon an internal explosion, emerging to ignite the surrounding atmosphere.

The contention of the first school was that in view of the venting devices the apparatus did not need to be so robust as would be required by the second method. One weakness of the venting method discovered in practice was that some venting devices became clogged or rusted and, in view of the fact that the structure was not designed to resist an unvented internal explosion, the result was often very dangerous. Moreover, incorrect assembly of the vent components may render it unsafe. Great care is therefore essential in the design, inspection and testing of vents, and where an enclosure can be designed to withstand the full internal explosion pressure without undue difficulty, the unvented pattern is generally accepted as being standard practice. For example, apparatus of small and medium size of a capacity up to about a cubic foot, usually presents no difficulty in this respect and is made unvented.

VENTING OR RELIEF DEVICES.

Venting devices operate generally by providing spaced gaps of predetermined dimensions to furnish paths for the heated gases to escape from an internal explosion, the passage of the gas through the gaps causing it to be cooled by contact with the metal surfaces. One method, known as the ring relief method, consists of a number of annular shaped rings bolted together with paths between, each path being not more than 1/50th of an inch wide. Another method consists of a spring biassed plate with a latitude of the same dimensions (*i.e.*, 1/50th of

an inch), which operates with an internal explosion. A third method employed grooved flanges to give pressure relief, but when machining the flanges it was difficult for manufacturers to determine that the safe limit of depth of groove was not exceeded.

The vent developed by the G.E.C. resembles the ring type in principle, but is rectangular in shape, and is built up of phosphor bronze strips 0·015in.

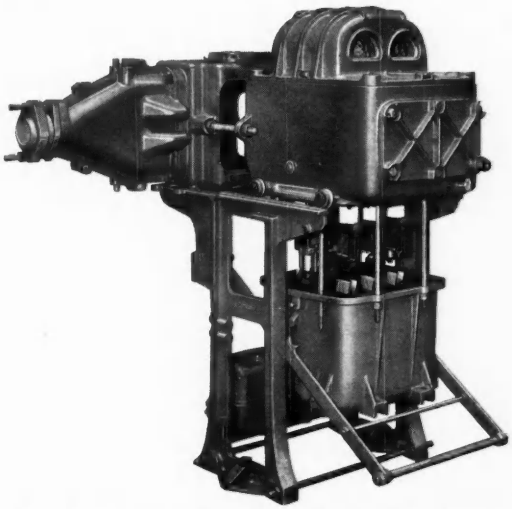


Fig. 2.—Flameproof switch unit with oil circuit breaker in isolated position and tank lowered.

thick, interleaved at the corners so as to be separated by spaces of the same depth. It does not open to the atmosphere, but is normally shut off by a spring-loaded valve, which not only prevents the ingress of dust and moisture, but closes instantaneously after relieving an internal explosion, and thus blocks the "suck back" of fresh explosive mixture. In this way, the repeated explosions which are characteristic of ordinary designs of vent, are obviated, and this form is actually safe with coal gas both inside and outside the enclosure containing over 50 per cent of hydrogen.

A method which is receiving attention at present, and has been tested, is to incorporate a plug member of a definite minimum length screwed into the unit body, in which very small holes are drilled axially along the plug, the small holes acting upon the gases in a similar way to the cooling flanges previously referred to.

It should be mentioned that no venting device has yet been satisfactory for oil-immersed apparatus because of the extremely small tolerance permissible in the joint to provide protection against the hydrogen produced. In modern practice, the majority of flameproof enclosures have close-fitting metal-to-metal joints either ground or smooth machined.

DEFINITION OF FLAMEPROOF ENCLOSURES.

A flameproof enclosure must withstand without fracture or permanent distortion an internal explosion of the gas with which it is to be used and provide a further factor of safety above that required by the testing authorities. This introduces the question of the various gases which occur under industrial conditions, and the variance in the safeguards applied to each gas.

For a long time the only gas generally used for testing purposes was methane (CH_4), the gas normally present in a coal mine; although the practice adopted when testing apparatus fitted with the G.E.C. vent was to use Birmingham coal gas. It was discovered by actual tests that apparatus suitable for use in methane would not be safe in atmospheres containing the vapours of pentane (C_5H_{12}). It was fairly obvious, therefore, that some standardized tests should be decided upon, and the authorities decided to separate the tests into three groups, namely I, II and III.

The first group, which affects mining apparatus, is tested with methane inside and outside. The second group, affecting apparatus for use in oil works, petrol plants, cellulose industries, etc., is tested with pentane gas inside and outside. The third group covers apparatus for use in town gas plants and by-product works, and is tested with coal gas inside and outside.

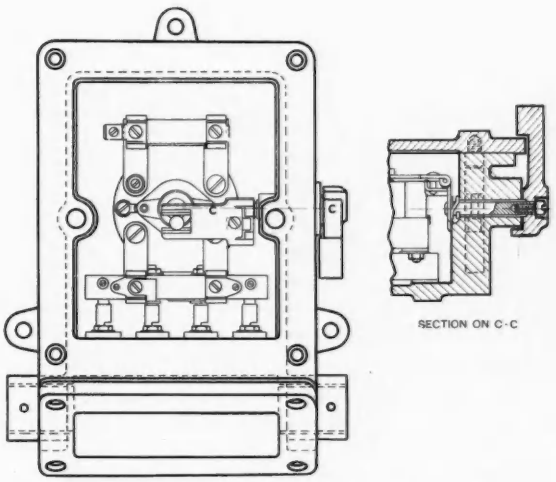


Fig. 3.—Flameproof switch and fuse box.

It may not be quite clear what is the distinction between methane, which is the normal product of coal seams, and coal gas, as previously referred to. The reason for the distinction is that commercial coal gas contains a large amount of free hydrogen, usually approximating to 50 per cent. and for test purposes a gas mixture of 40 per cent. methane and 60 per cent. hydrogen is employed.

There are two fundamental factors to consider in flameproof apparatus. First, the apparatus must

be of sufficient strength to resist any internal explosion and, secondly must be provided with means to cool down any escape of gas from such an explosion before it meets the surrounding atmosphere. With regard to the first requirement, it can be accepted that a suitable design at present rests nearly as much upon the results of empirical tests as upon mathematical calculation, since, although the rate at which the explosion pressure varies with its volume is known, the relationship is affected considerably by incidental factors. The explosion pressure manometrically measured varies with the shape of the vessel, the presence of compartments or internal obstructions which give rise to piling pressures and, to some degree, upon the elasticity of the metal of which the vessel is made.

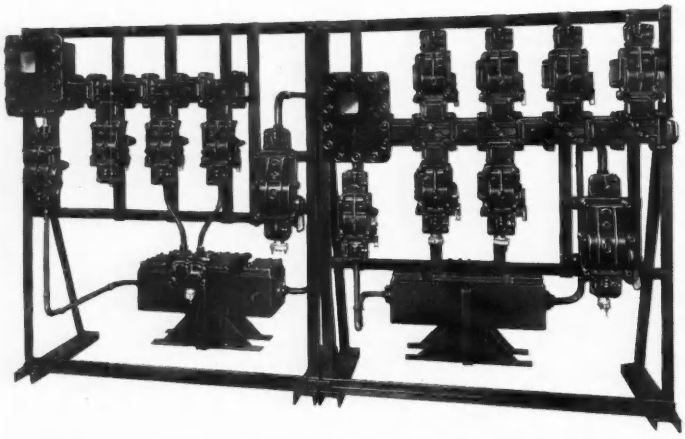


Fig. 4.—Flameproof ironclad switchboard comprising air break switches, busbar chambers and flameproof transformers.

TESTING OF APPARATUS.

The Mines Department Testing Station, Buxton, demands that the structure shall be guaranteed to withstand a pressure of 50 per cent. above the recorded explosion pressure, and reserves the right to have all or any apparatus hydraulically tested to that figure. It is not definitely stated that such a test shall be continuous over a period, in fact an impulse test to the required pressure is welcomed as approaching closest to the effect of an explosive wave. It has not been found that pentane, coal gas or hydrogen and air mixtures when exploded produce pressures very much greater than methane, but the rate of combustion is very much more rapid.

FLANGE TOLERANCES.

As stated previously, it has also been found that flanges with a certain tolerance between the machined surfaces will quench a methane explosion but not one of pentane, or coal gas. A great many experiments were made with pentane, and it was decided that the maximum joint tolerance of 0·02in. permissible in methane had to be reduced to 0·016in., while in apparatus filled with hydro-carbon oil with either methane or pentane surrounding it, the tolerance must not exceed 0·006in. Quite recently a certain amount of doubt has been cast upon even the latter figure. The additional danger in the case of oil-immersed apparatus is due to the formation of hydrogen and acetylene as a result of the arcing between the contacts.

At the present time the tests for coal gas are provisional and the gap tolerance has been fixed at 0·01 inch.

These tolerances in gap width are, of course, associated with a flange width, and in all cases (excepting very small telephone or other enclosures) are determined as follows :—

When the volume of the empty casing exceeds 100 cubic inches, the width of the flange shall not be less than 1in., and where the volume is below 100 cubic inches a width of $\frac{3}{4}$in. is permissible.

For close metal-to-metal joints, the presence of bolt holes may be ignored, provided the edge of the hole is not less than $\frac{3}{8}$in. from the inner edge of the joint surface.

In fig. 3 a drawing of a flameproof switch and fuse box is shown which has been certified for Groups I, II and III. In this design it will be seen that advantage is taken of the small volume of the enclosure to reduce the width of the flanges to $\frac{3}{4}$in. A flameproof ironclad switchboard comprising air break switches and flameproof transformers, is shown in fig. 4.

DIAMETRAL CLEARANCES.

Where shafts or spindles are intended to pass from outside into the flameproof enclosure, the same restrictions apply to the length of bearing and diametral clearances as in the case of the flanges. This is also shown in fig. 3, where the switch spindle passes into the enclosure. In all cases where an oil duct or channel is cut in the shaft within the bearing, the length of the bearing must be such that the minimum bearing or protective surface must be exclusive of such duct.

GLASS WINDOWS, ETC.

For certain types of apparatus such as lamp fittings, switchboards, etc., in which glass containers or windows must be incorporated, special precautions have to be taken. In the first place, the glasses have to be bedded in cement, which is required to be one of certain specified types that can be relied upon not to crack or shrink after insertion. Recognized and satisfactory mediums are "Keene's"

cement and a glycerine-litharge mixture. The glass has also to be maintained in position by clamps or screws and must not rely upon the cement alone. Fig. 5 shows a lamp fitting which illustrates the method used in the case of a well glass, while fig. 6 shows another method employed for securing observation windows in a remote control flameproof unit.

FLAMEPROOF MOTORS.

The foregoing remarks have referred to ordinary flameproof enclosures, where the units are generally of simple construction and no special amount of wear has to be considered.

A rather different standpoint must be taken when constantly moving shafts have to be considered, such as those of motors, for it is obvious that without very strict maintenance the diametral clearance between the upper side of the shaft and the bearing must be affected by wear. One method of overcoming this weakness is the adoption of a labyrinth gland in which the passage of the gas from

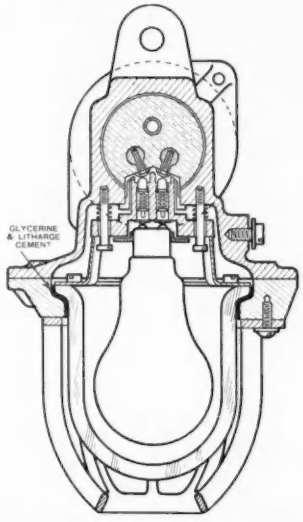


Fig. 5.—Sectional drawing of flameproof lamp fitting showing method of securing the glass.

inside to outside has to pass a tortuous passage due to the formation of the gland. This is shown in fig. 7. This type of gland has been certified for use with ball bearings, and further tests have been carried out on journal bearings. As may be seen, the safety factor in this type of gland does not depend upon a very small gap tolerance, but rather on the tortuous passage which the heated gas would have to take, and the resultant cooling effect. The width of the clearance at present allowed between the moving members is approximately $\frac{1}{8}$ of an inch both vertically and laterally. This, therefore, gives a very reasonable latitude for wear. Tests are, however, being made to ascertain the maximum clearances permissible. The gland consists of three members, of which one member, fixed on the shaft, rotates. This member is fitted with a number of annular fins which are staggered in a radial direction and engage in recesses formed by similar fins in the stationary members attached to the body of the motor. Another type of protection is the use of cartridge bearings, in which an outer ring is fitted on the outer bearing race and secured in position by two bearing caps. The bearing, therefore, is contained within a grease-filled chamber which gives the necessary protection. Another advantage claimed for this type of bearing is its adaptability for easy assembly without possible damage to the outer race. This race cannot be distorted and damaged as the caps prevent it from rocking.

CONDENSATION.

An important point to be considered in all flameproof apparatus is the condensation factor. This is particularly important in large motors and other apparatus in which continuous temperature changes take place. During certain periods, such as when the motor is running, the internal air is heated and expands, this expansion being relieved either through the flange or through the bearings. When the resultant cooling of the apparatus takes effect, upon the stopping of the motor or the switching off of the heating medium, the internal air contracts and allows the surrounding air to come in. This air may be and probably is humid, and in time condenses and collects in the lower part of the container. Various devices have been tried to counteract this effect. An early method was to use a deliquescent chemical such as caustic potash kept in a tray, which absorbed the moisture within the container. This functioned quite satisfactorily when the absorbent was changed regularly, but if this was neglected, the chemical usually attacked the metal with disastrous results. Another extensively used method is to spray the interior with an adhesive liquid and immediately dust it over with powdered cork. This has the effect of covering over the cooling surface and providing a certain absorbing factor. A modern method, which has been designed and

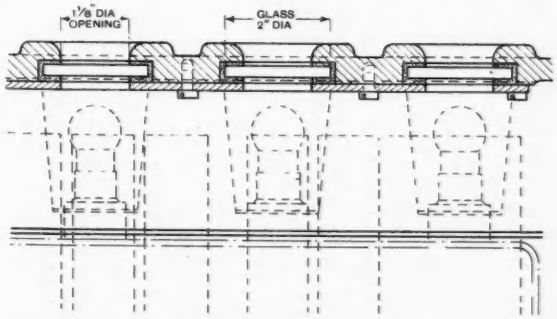


Fig. 6.—Method employed for securing observation windows in a remote control flameproof unit.

tested at Buxton, is to utilize a brass plug screwed into the lowest part of the unit. Three holes are drilled axially in the plug which is at least one inch long, these holes being 3/64in. diameter. It has been ascertained by test that this type of plug would drain out a cavity with a temperature rise of the internal air of 10°F.

In addition to ordinary corrosion in flameproof gear it is necessary to guard against another type of corrosion. Normal arcing of air-break contactors

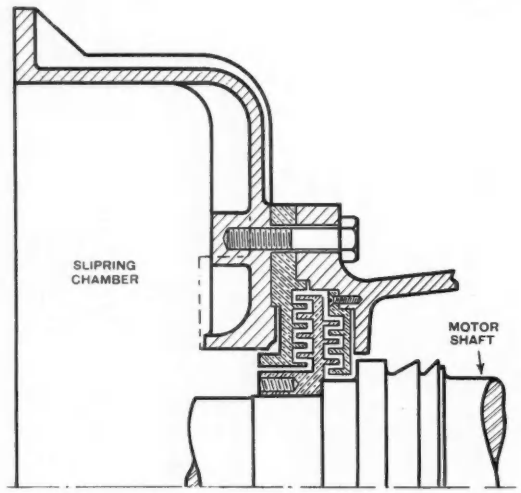


Fig. 7.—Labyrinth gland employed on a flameproof motor shaft.

generates nitrogen peroxide gas (NO_2) which is retained within the chamber. Nitrogen peroxide in itself does not seriously affect metal, but the presence of a humid atmosphere converts it into a mixture of nitric and nitrous acids and this is definitely corrosive. Unless the case can be sufficiently ventilated to enable these gases to diffuse away, the only solution other than methods of absorption of the water is special plating of the exposed metal parts to resist such corrosion.

TEMPERATURE RISE.

It has been mentioned that Group II covers apparatus for use in pentane, and this also covers cellulose industries, in which spraying or the making of cellulose paints demands flameproof apparatus. Here, however, a very important feature must be observed, and that is the possible temperature rise of such apparatus. This applies to lighting, heating, and other gear in which heating may occur. In the Cellulose Solutions Regulations, 1934, Clause 5 (B) enacts that "All heating and electrical apparatus including lamps, fittings and resistances liable to attain a temperature of 180°F. shall be so situated or so protected as to prevent the depositing thereon of any solid residues resulting from the manufacture or use of cellulose solutions."

This broadly affects any apparatus to be used on, in, or near to any spraying booth or store room. Conceivably, if a lamp or other fitting is placed some reasonable distance away, say 8 to 10 feet from a booth, such booth being exhausted by its own fan, no exception would be taken to a non-flameproof fitting.

The temperature of 180° F. specified by the authorities represents a rise of 90° F. over an ambient temperature of 90° F. This figure of ambient temperature has been fixed by the Mines Department. In some tests carried out on lighting fittings at the G.E.C. Research Laboratories it was found that the temperature rise is affected only slightly, by the ambient temperature—the rise falling slightly as the ambient is increased. This may be shown by the following table:

TESTS IN OPEN ROOM.

Ambient Temperature	Temperature Rise	Maximum Temperature
46° C.	48° C.	94° C.
13° C.	53° C.	66° C.

TESTS IN DRAUGHT FREE ENCLOSURE.

Ambient Temperature	Temperature Rise	Maximum Temperature
40° C.	53° C.	93° C.
15° C.	55° C.	70° C.

TESTING TEMPERATURE RISE.

When apparatus is submitted for approval in circumstances in which a temperature rise is possible, a test and declaration must be made by the manufacturer of the temperature rise. Until recently it was a particularly weak point that no specified method of testing was stipulated, and therefore a declaration

Fig. 8.—A flameproof type of floodlight designed to take a 500 watt general service lamp.

might honestly have been made of a certain temperature rise, when by a different method of testing, a more unfavourable rise would be recorded. A comparative test was made on the fitting previously mentioned by thermo-couple and thermometer. The bulb of the thermometer was in contact with the glass but no covering was placed over it. The temperature given by the thermometer was 11°C. lower than that given by the thermo-couple. It is possible, therefore, that if temperatures are measured by a thermometer, a fitting may be permitted which does not actually comply with the regulations. A properly conducted test should be made in draught free conditions by efficient thermo-couples.

The Mines Department have recently circulated a document, No. M.112, in which they recommend a definite procedure for temperature testing, involving the use of efficient thermo-couples with screen enclosures.

In regard to the temperature rises, it is quite obvious that as flameproof apparatus is necessary in industries other than that of cellulose spraying, where the temperature rise is limited, certain units can and do obtain a Group II or Group III Certificate, which enables them to be used in hazardous situations other than cellulose spraying, where there is no reasonable limit to the temperature rise. One of these units is shown in fig. 8. This is a 500 watt flameproof floodlighting unit, which, in order to comply with the requirements of the Department, is marked "Not for Cellulose Industries."

FLAMEPROOF HEATERS.

Fig. 9 shows another example of a flameproof unit that normally would not pass the temperature

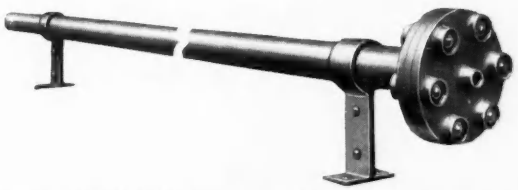


Fig. 9.—Flameproof tubular heater for use in cellulose industries.

limit—this is a flameproof tubular heater. This has also received the Group II Certificate and is permissible in cellulose industries, but the restriction in this case affects the wattage rating, and where used in cellulose industries this must not exceed 28 watts per foot run.

JUNCTION BOXES.

In all flameproof type apparatus means has to be provided for connection to the supply mains, and the authorities demand that the terminal or junction box shall be a separate flameproof entity, sealed off from the main chamber by a flameproof partition. Usually, this consists of a metal partition wherein are fixed the connecting bolts between the two chambers. These bolts may be fixed as shown in fig. 10 and housed in insulated sleeves: the length of path through the sleeve itself through the partition must be a minimum length of 1 inch. Also, the clearance between the bolt and sleeve, and sleeve and casting must be of the minimum tolerance relating to its particular group. Where conduit is to be used means must be provided for the screwed entry of the conduit to the terminal chamber for at least an inch. When cable is to be used without conduit, it must be at least single armoured to preserve the flameproof feature of the system, and provision made

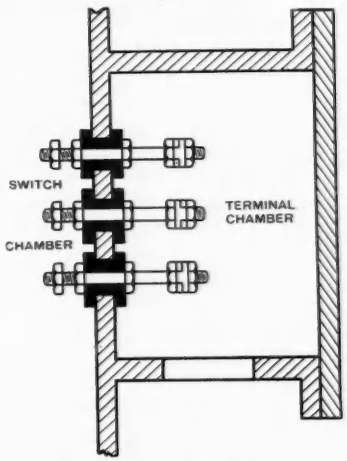


Fig. 10.—Flameproof terminal chamber showing method of fixing studs.

for anchoring the armouring and for the effective sealing of the cable dielectric. In order to accomplish this effectively the insulation should be taken off for a short distance within the sealing box, as shown in fig. 11, and the compound poured in. This enables the compound to adhere to the conductor itself and prevents moisture percolating inside the cable. It is often advantageous to solder the conductor solid at this point, thus making certain that even the interstices of the cable conductor are filled.

CONDUITS, ETC.

A system that is required to be completely flameproof depends as much on the ancillary apparatus as it does on the main members, and so attention must be given to such apparatus. All conduit should be of the solid drawn variety, no welded conduit being permissible. The conduit boxes, junction bends, etc., should be approved similarly as being flameproof.

Each screw thread should be at least 1in. in length and screwed home. Provision should be made at each junction to the switch or conduit box to lock the conduit after insertion to prevent inadvertent withdrawal. This may be done by a

grub screw or lock nut. In short, the whole of the wiring system should be encased in a solid weldless metallic shroud.

A subject which is now receiving some attention is the question of the effectiveness of a conduit

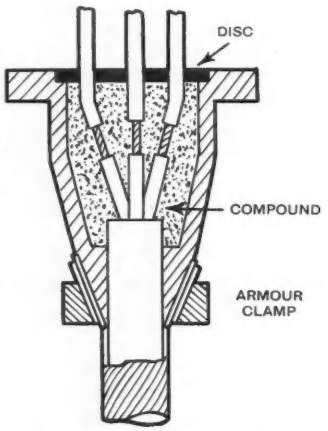


Fig. 11.—Method of anchoring and sealing cables inside a flameproof cable box.

system completely connected up with flameproof enclosures. It should be appreciated that a conduit entry into a flameproof enclosure is permitted on the understanding that the other end of the conduit also terminates in a flameproof enclosure, and that the conduit itself must be of the solid drawn or weldless variety.

It has been shown that the width of the flange is dependent upon the volumetric content of the chamber in the apparatus. Thus, a flange having a width of 1in. is required when a conduit system is joined up to a terminal box which has a cubic capacity not exceeding 144 cu. ins. Immediately the conduit system is connected to the terminal box the volumetric content of the container naturally increases by the amount equal to the volume of the conduit and a rather elastic volume has therefore to be considered. It might be that the whole of the conduit system would become filled with inflammable gas, and an explosion within one of the chambers would probably give rise to high piling pressures in parts of the system, with possibly serious results.

It seems that the only radical solution to this problem would be to sectionalise the conduit system in order to minimise the volumetric content and the resultant piling up of pressures. This could be accomplished by arranging that the system as a whole is sectionalised by inter-section and junction boxes, filled with a plastic compound which can be pressed into the section and junction boxes after the wiring has been completed.

It is the practice in America to sectionalise these systems by pouring a fluid compound into a "U" shaped member situated at points along the system, but in view of the difficulty sometimes experienced in pouring in this compound in inaccessible places, it is probable that the use of plastic compound is more convenient.

METHODS OF BOLTING, ETC.

One of the most important features of flameproof apparatus is the method of securing the flanges, doors, well glasses, etc., and particular attention must be paid to the design of such gear to ensure that the omission of a stud or bolt will not destroy absolutely the flameproof feature. To this end, flanges as far as possible should be designed so that the heads and nuts of the bolts are external to the apparatus, also, when studs must be used, the screwed stud hole in the main body should be bottomed or blinded in some way. This can be done by drilling the hole partly through the metal wall, or if drilled through, the bottom section of the hole can be plugged by a screwed plug spot welded in position to give the greatest security.

Another convenient method is shown in fig. 12. This applies more particularly to fabricated steel casings, where it is often necessary to weld a bar of steel inside to give the necessary bottoming. The flange or plate is drilled and tapped and a set bolt or stud screwed in, the head being within the plate or flange as shown in B or C. The stud should be rivetted or welded, as shown. Another method of bottoming the screw portion by welding a block of steel and drilling and tapping it is shown in A.

An alternative method has been suggested (fig. 13), in which a small cylindrical piece of steel drilled and tapped to size is rivetted into a larger hole in the plate. This facilitates removal, when necessary, if the thread is damaged.

The heads of all nuts and screws ordinarily used for frequent inspection or renewals must be shrouded to prevent as far as possible any unauthorized

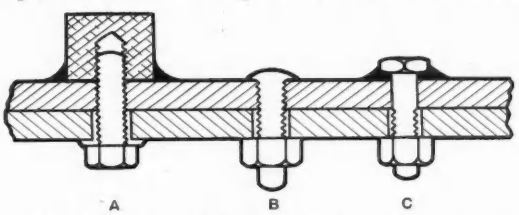


Fig. 12.—Bolting methods used on flameproof flanges.

removal, and fig. 14 shows two alternative ways of securing these heads. In fig. 14A, a shrouded ring is cast in one piece with the body and in fig. 14B, a channel member is used for guarding a number of bolts in line.

INTERLOCKS.

Another important feature in flameproof apparatus is the question of opening up the enclosure

under load or with the current on. It is obviously a very dangerous practice, and wherever possible the Mines Department naturally demands a system of inter-locking with either a switch or other means of isolation. It is very difficult to design an interlock which will ensure that the enclosure shall be flameproof before the apparatus can be operated. Practically all interlocking systems will allow the cover bolts, etc., to be loosened or taken out while the switch is on, merely preventing the cover door from being opened. It will be seen, therefore, that these methods while being safe from the point of view of the preventing of shock, are useless as a means of ensuring that the apparatus is flameproof. It seems that the only satisfactory safeguard is care in installation, maintenance, and use.

MAINTENANCE AND USE.

Maintenance and use are matters of the utmost importance. It is quite conceivable that no care in design and manufacture can ensure adequate protection without the necessary care in maintenance. The tolerance of, say 0·01in. required for Group III can be rendered abortive so easily if the machined surfaces of the joints are damaged or not kept scrupulously clean. Again, a worn bearing, if it is not fitted with a compensating labyrinth gland obviously destroys the factor of safety. One or two bolts left out of a flange or cover, while not immediately affecting the flameproof qualities, reduce materially the resistant strength against a possible internal explosion.

Lighting fittings in cellulose industries unless kept clean very easily attain a temperature above that specified as being safe. Inserting a lamp of a greater wattage than that for which the fitting is designed has the same effect.

The use of cables which are smaller in diameter than those intended for the terminal chambers, and the omission of sealing the dielectric where necessary

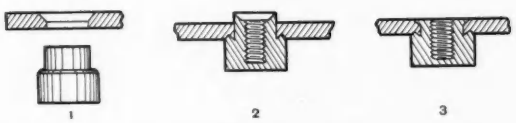


Fig. 13.—Alternative method to fig. 12A for securing flanges by means of a screw-in stud.

also defeat the object aimed at. It would thus appear that the maintenance of such gear may actually be the most important factor.

The question is often asked as to where certified flameproof apparatus is required. This is defined in Collieries by Regulation 132, which enacts that flameproof gear shall be used where there is a likelihood of the presence of inflammable gas. In other industrial situations it is not as yet so definitely regulated, but the authorities are rapidly deciding where such apparatus is necessary. It can be taken for granted that wherever any inflammable liquid or gas is stored flameproof gear should be used. This would cover petrol and oil stores, paint factories and stores, and cellulose spraying stores. Such apparatus should also be used in garages, particularly where any petrol is stored, in gas works, by-product plants, cellulose spraying, cleaning and dyeing establishments, explosive manufactories and stores. Reference has been made earlier in this article to the use of flameproof gear in connection with spraying booths, but further information may here be added. It was previously pointed out that where the booth is self-ventilated by a fan, only the light fixed on or immediately above the booth, and the motor which drives the fan need normally be flameproof, and that if a non-flameproof light were placed 8 to 10 feet away this arrangement would be permissible. This is correct in most cases, but there may be instances in which the articles after spraying are kept stocked in the same room. The possibility exists that the highly volatile solvent drying off would rise into the room and create a possible danger. Such cases have to be considered, each on its merits, with due consideration to the air change in the room and the volatile solvent content at any period of the day. With regard to motors for factory drive where danger exists, consideration should be given to the question whether unit drive of machines is necessary or desirable or whether a system of shafting drive would be preferable. In the first case, each motor with its ancillary control apparatus must be flameproof, but in the second case it is quite conceivable that the main motor can be situated in an engine room outside the danger area, and need not be of flameproof design.

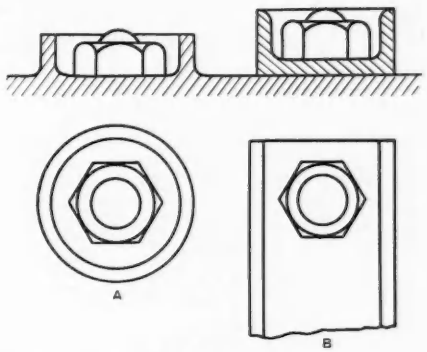


Fig. 14.—Alternative methods of shrouding bolt heads.

As regards heating, no electrical heating apparatus can be used in dangerous situations other than the tubular heaters previously referred to, and the reduced wattage per foot run only applies to cellulose

spraying. In other situations such as garages and petrol works the normal rating can be used.

CASES OUTSIDE GROUPS.

The apparatus dealt with so far is suitable for the gases which are included in Groups I, II and III. There are, however, other gases and liquids used in industry of a greater explosive susceptibility than those previously mentioned, and with a very much lower point of ignition, such, for example, as carbon bi-sulphide.

It is presumed that as far as joint tolerances are concerned apparatus which would pass the hydrogen test, that is, with the flange tolerance reduced from 0·01in. to 0·006in. would be equally satisfactory for these gases and vapours, but as yet this has not been definitely laid down. It is quite certain, however, that flameproof apparatus in which heat is generated (such as lighting fittings, motors, transformers, etc.), and the temperature rise of which is limited for approval for cellulose industries, would not necessarily be suitable for the above-named gases on account of their low point of ignition. A great deal of research is still going on in regard to special apparatus of this type, and it is not worth while at this juncture to try to anticipate what tolerances and maximum temperature rises are likely to be recommended for these other gases. It will be appreciated that even in Group III the tests are now only provisional, although the maximum joint tolerance has been defined.

The Ministry of Health Authorities are at present seriously concerned with the number of accidents due to anaesthetic explosions in operating theatres and rooms, caused by the ignition of the anaesthetic by electric apparatus. These anaesthetics may be ether-air, or ether-oxygen, ethyl chloride, A.C.E. mixture and ethylene-oxygen. In cauterization, the heat of the cautery may be in itself sufficient to cause combustion of ether vapour. Ether-oxygen vapour can quite readily be ignited by contact with hot metal at 300°-305° C. a temperature much *below* visible red heat.

A further danger is the possibility of static discharge from rubber-tyred trolleys or portable electrical equipments.

Research is going on in this direction but the difficulties presented are considerable, particularly in regard to inspection lamps for laryngeal operations, etc. The size of the inspection lamp is obviously limited and this presents a difficulty in designing a robust flameproof fitting.

At present it appears that the only satisfactory safeguard is to establish local ventilation to diffuse the anaesthetic fumes and prevent the actual contact of such fumes with the light or cautery. To obviate the danger of static discharge all trolleys should be continuously earthed with an efficient earth main in order to prevent the retention of a charge.

IDENTIFICATION OF FLAMEPROOF GEAR.

Hitherto in this article consideration has been given to the requirements of the Authorities and the technical details of these requirements relating to certified apparatus; in conclusion it is proposed to consider the identification of such certified apparatus.

The Mines Department Testing Memorandum No. 4 states that the Mines Department are prepared to consider applications from manufacturers for licences to use a certain mark on apparatus of types in respect of which flameproof certificates have been issued. The issue of a flameproof certificate does not confer permission to use the mark unless a formal licence to use it has been granted to the manufacturer. The mark consists of an outline of a crown, with the letters FLP therein, and it is a condition of the certification that apparatus marketed as being of type certified by the Mines Department shall have permanently marked upon it:—

(*a*) The name of the manufacturer registered with the department as regards the certificate in question.

(*b*) The name or type number of apparatus, as specified on the certificate.

(*c*) The number of the FLP. certificate and the group number or numbers indicating the gases or vapours covered by the certificate.

This marking is in addition to the crown with the FLP enclosed therein.

It is obviously important that apparatus used under conditions which demand a certified group test should be stamped with that particular group number. At present there is some little ambiguity amongst the general body of users as to the particular group or type of apparatus that is necessary to be used under the varying conditions now prevalent in industry.

Switchgear Extensions at Thorpe Power Station, Norwich.

By C. J. O. GARRARD, M.Sc., A.M.I.E.E.
Switchgear Dept., G.E.C. Engineering Works, Witton.

The author describes an interesting installation of 6·6 kV switchgear, having the unusually high breaking capacity for this voltage of 1,000,000 kVA. As he points out, it is probable that a breaking capacity of this figure is the maximum for which it is economically practicable to construct 6·6 kV switchgear. The peak making current of 220,000 amperes imposes very large mechanical stresses upon the whole structure of the gear.

In fact, for such a large breaking capacity at 6·6 kV, the design of the breaker, to withstand the electrodynamic forces on short circuit, involves greater problems than that of the arc control device.

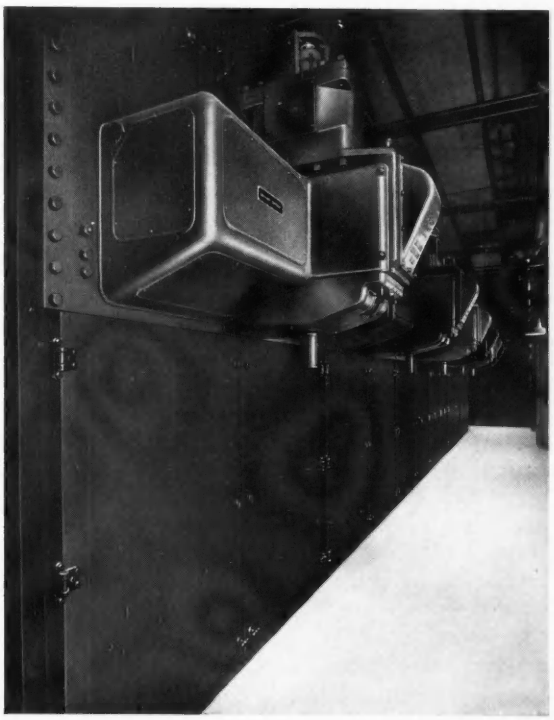


Fig. 1 (*left*).—**6,600 volt, 1,000,000 kVA oil circuit breaker cubicles at Thorpe Power Station, Norwich, showing the operating solenoids.**

IMPORTANT extensions to the main switchgear at Thorpe Power Station, Norwich, have recently been completed. They include the installation of a new 6·6 kV, 1,000,000 kVA stonework cubicle board and additions to the existing 6·6 kV, 500,000 kVA gear.

Before these extensions were made, the main switchgear consisted of twenty-four stonework cubicles, designed for a breaking capacity of 500,000 kVA with duplicate busbars. A new 1200 ampere feeder equipment and six skeleton equipments consisting of busbars and busbar isolators only, have now been added to the 500,000 kVA gear and will be used for feeders to be installed later. Two three-phase sets of busbar isolators are also provided for sectionalising the "Engine Room" or main bars, the "Riverside" or reserve bars being continuous throughout their length.

No further extension to the old 500,000 kVA gear is now possible, the remaining space in the building being occupied by the new 1,000,000 kVA, 6,600 volt switchgear, which is the main subject of

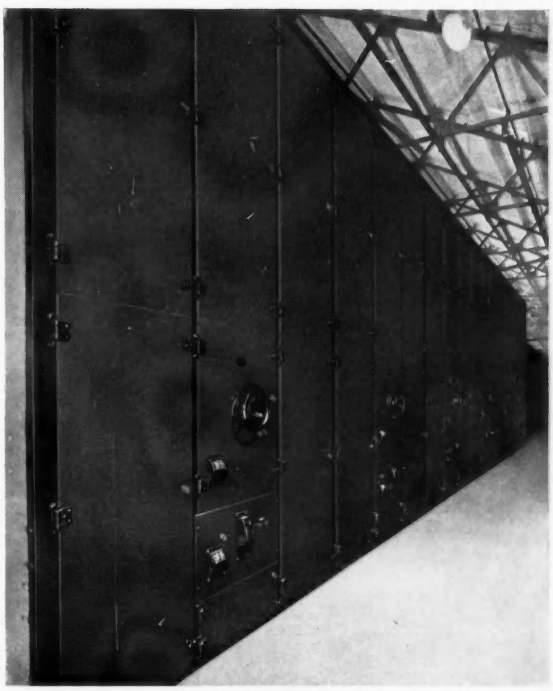


Fig. 2.—Stonework cubicles housing the main busbars and busbar isolating switches.

this article. The increase of the breaking capacity of the new switchgear from 500,000 kVA has been necessitated by the installation of a new 30,000 kW 6,600 volt turbo-alternator (No. 6) and the prospective installation of a second similar set (No. 7) at some future date.

In order to avoid overstressing the existing 500,000 kVA gear, the connection between its main (Engine Room side) busbars and the main bars of the new gear is made by means of current limiting reactors.

The auxiliary bars of the 1,000,000 kVA gear are continuous with those of the 500,000 kVA gear throughout the length of the station.

NEW EQUIPMENT: GENERAL DESIGN.

The new switchgear, figs. 1 and 2, consists of six equipments, one for controlling the connection to the limiting reactors, one for the new 30,000 kW alternator, No. 6, and two for the 30,000 kVA Grid transformers, together with busbar sectionalizing and busbar coupling circuit breakers (fig. 3). The dimensions of the site are only sufficient for the installation of one further equipment which will serve for the control of the future alternator No. 7. The new switchgear is provided with duplicate sets of busbars; the "Engine Room" set is in two sections connected together through the busbar section breaker and is coupled to the 500,000 kVA gear by three single phase reactors, while the "Riverside" auxiliary busbars are continuous throughout their length and are connected direct to the auxiliary bars of the 500,000 kVA switchgear by means of a busbar crossover.

The switchgear is housed in a separate switch house adjacent to and alongside the main turbine house. It has two floors; on the upper of these are the cubicles containing the oil circuit breakers, fig. 1, and the busbars and busbar isolators, fig. 2. The cubicles for the instrument transformers and feeder isolators are on the lower floor. The busbar section and coupler circuits are accommodated on the upper floor only, no cubicles being necessary on the lower floor for instrument transformers or isolators.

Underneath the lower floor is a basement in which are located the cables and connections between the switchgear and the alternator terminals. Fire-proof sectionalizing walls, extending the whole way across the switch room, are erected on each side of the 1,000,000 kVA busbar section breaker. These walls are virtually continuous right through the cross connection of the cubicles, as they are in line with the stonework barriers through which the busbars pass. The barriers are maintained practically gas-proof by the provision of brass inserts in the ends of the busbar bushing insulators, leaving only a small clearance for the expansion of the busbar.

An oil drainage sump with pebble filling under a metal grid is provided below each circuit breaker. These drain into a common pipe leading to a sump outside the building.

CONSTRUCTION OF CUBICLES.

The cubicles consist of a steel channel section framework filled in with moulded stone panels 3in. thick. In view of the very heavy currents involved, aluminium channel sections are included in the busbar cubicle facings at the rear of the oil switch cubicles to prevent possible heating in the steel framework due to induction. All the remaining framework, doors and plates are of steel. Each cubicle is subdivided so that the three phases are completely isolated, the dividing walls extending downwards to meet the circuit breaker top plate which is common to the three phases. Below the top plate the three separate oil tanks, one for each phase, constitute a sufficient subdivision. A typical cross section through the switch cubicles is shown in fig. 4, which represents the equipment for the control of the alternator.

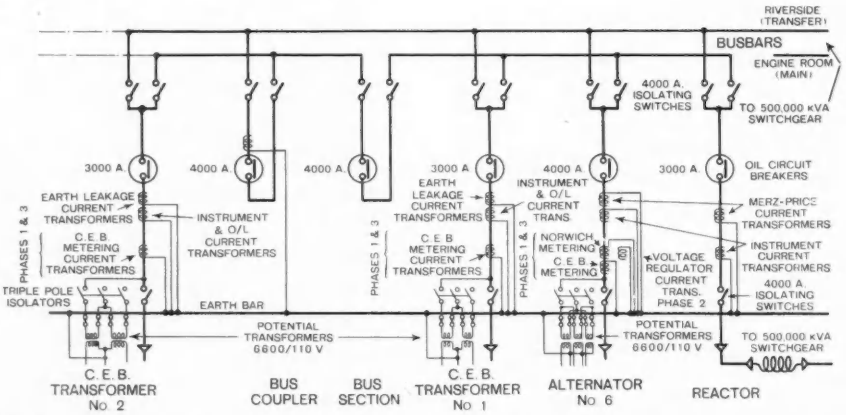


Fig. 3.—Single line diagram of connections of the 1,000,000 kVA switchgear at Thorpe Power Station, Norwich.

BUSBARS AND CONNECTIONS.

The busbars are made of copper tube with a cross sectional area of 6 sq. in. and are supported by compression type isolators arranged so that cantilever forces upon the insulators are avoided. Each insulator assembly carries a brass casting which encircles the bar and is attached to the insulator caps by means of bolts passing through jacking sleeves. The busbar is also supported inside the ring on four jacking screws, the whole arrangement allowing easy compensation for irregularities in the stonework. The bars are free to slide through the rings on expansion due to heat. Extension and contraction are taken up by an expansion joint at the mid point of the auxiliary bars and by the freedom of the conductors to slide through the rings on the tops of the insulators mentioned above.

The joints between the sections of copper tube forming the busbars and connections are made by means of split and bolted muff couplings, the inside surfaces of which are screwed so as to ensure intimate contact with the tubes.

The connections for the 4,000 ampere circuits have a cross sectional area of 3·95 sq. in. and those

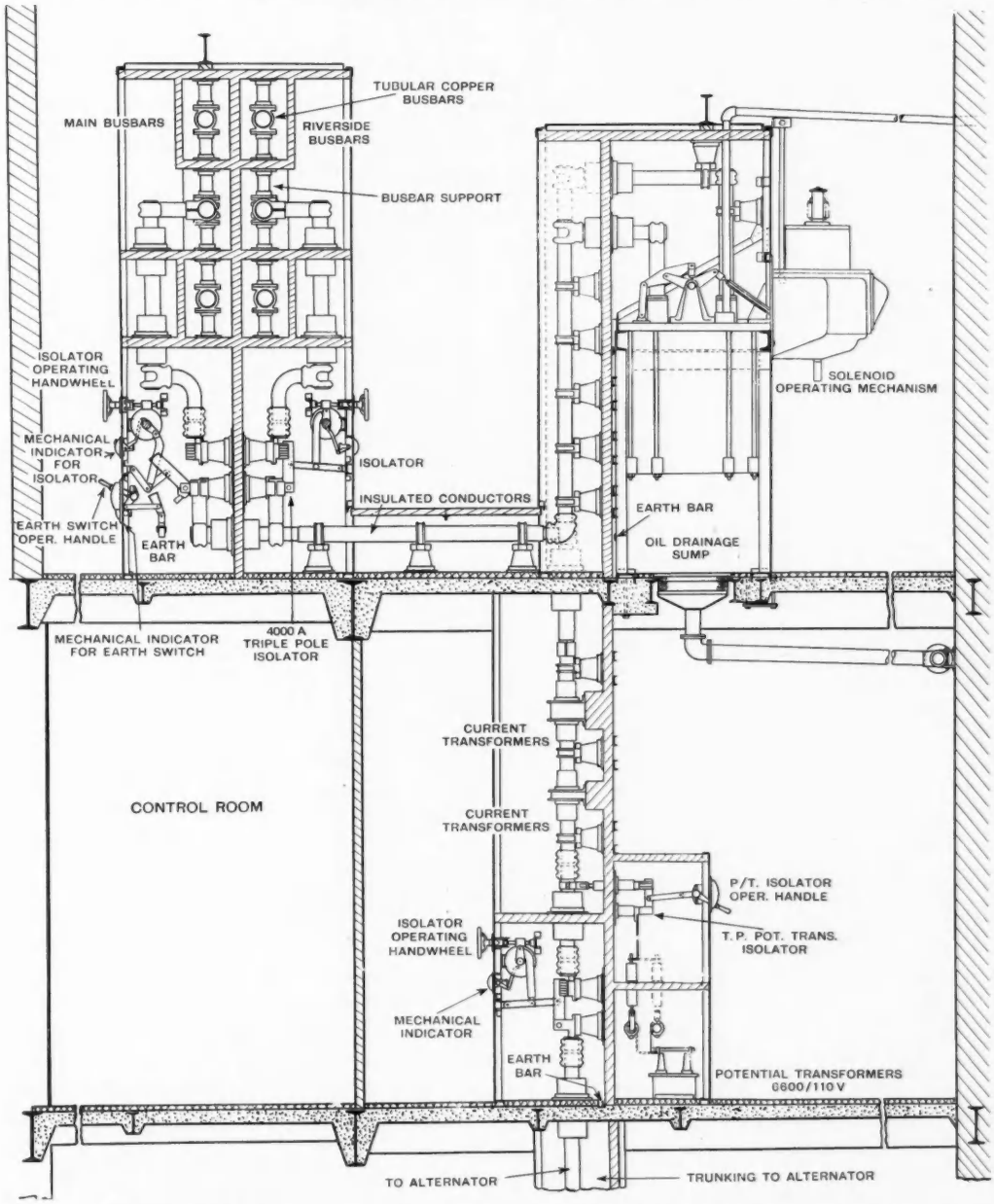


Fig. 4.—Cross-sectional diagram of alternator switchgear equipment at Thorpe Power Station, Norwich.

for the 3,000 ampere circuits a cross sectional area of 3·5 sq. in. The connections are supported by exceptionally massive porcelain post insulators mounted at a uniform distance of 17ins. The maximum force between adjacent connections, in the event of short circuit, is 1,600 lbs. per foot run. Each insulator may therefore be subjected to a cantilever force of 2,720 lbs. As its ultimate strength

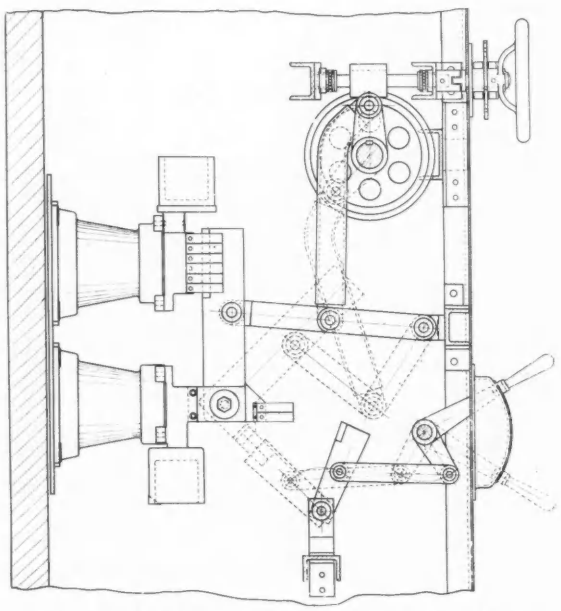


Fig. 5.—4,000 ampere gang-operated isolator with earthing switch.

is 10,000 lbs., the factor of safety is nearly four. Each insulator carries a cast brass ring through which passes the conductor tube, as in the case of the busbar insulators.

The connections to the alternator are made of copper tube and are housed in a moulded stone trunking with three compartments, running between the isolators and the alternator foundation block and supported on steel joists.

Between the end of the trunking and the alternator terminals, the conductors are run through a common duct in the foundation block. In the duct, the spacing between the conductors is of necessity small and in the event of a short circuit the electrodynamic forces are correspondingly high, Bakelite bracing bars are therefore provided at intervals to take up the forces between the conductors.

The grid transformer and reactor equipments are generally similar to that for the alternator but the outgoing connections are made in cable.

CURRENT TRANSFORMERS.

The bar type current transformers are arranged as bushings and consist of porcelain tubes which slip over the conductors. The core and secondary windings encircle the porcelain tubes.

ISOLATING LINKS AND EARTHING SWITCHES.

The busbar and feeder isolating links, fig. 5, are ganged in sets of three and are operated by hand-wheels on the front of the cubicles, fig. 6. The

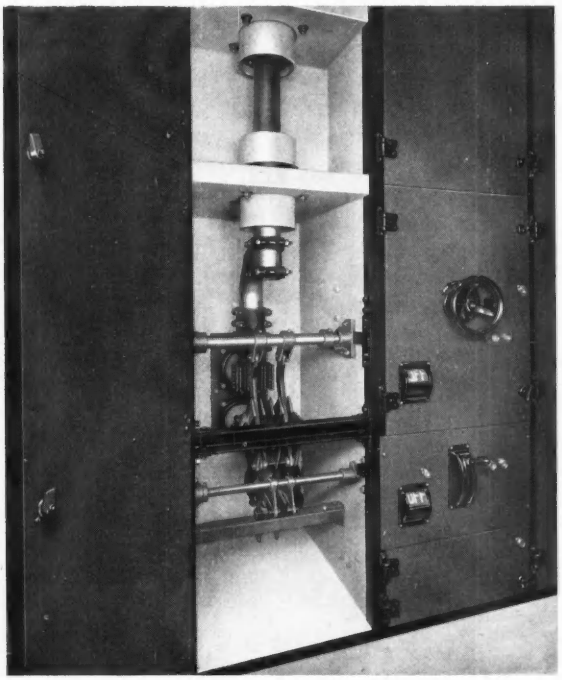


Fig. 6.—View of one phase of the 4,000 ampere gang-operated isolating switches.

connections between the busbar isolators and the oil circuit breakers are run in a crossover covered by moulded-stone slabs forming a false floor. Where they pass through this false floor the conductors are wrapped with synthetic varnish bonded paper. The isolators are all rated to carry 4,000 amperes and each has 5 blades in parallel. The hinged contact clips are of the standard type, but the break contact clips consist of 30 pairs of finger contacts, fitted with backing springs which dispense with the need for any clamping device to prevent overheating, and reduce the force required to operate the isolator. The links are operated by a worm and wheel mechanism, the wheel rotating a main shaft connected to the blades of the isolators by means of a toggle.

As it was specified that each equipment should be capable of being earthed through its respective oil circuit breaker, earthing switches are fitted to the busbar isolators on the engine room side. These earthing switches are also ganged in sets of three and are operated externally by means of a handle

on the front of the cubicle. Both isolators and earthing switches are provided with mechanically operated position indicators.

INTERLOCKS.

The grid transformer circuits are provided with a complete system of interlocks including the isolators, oil circuit breakers, earthing switches and cubicle doors. For the alternator, reactor, bus section and bus coupler circuits a modified scheme is provided, as it was specified that it must be possible to change over any of these circuits from one set of busbars to the other whilst on load. All interlocking is carried out by means of Castell locks and keys.

OIL CIRCUIT BREAKERS.

The oil circuit breakers for all equipments are of the same design and are rated at 4,000 amperes in the case of the alternator bus-section and bus-coupler circuits, and at 3,000 amperes in that of the grid transformer and the reactor circuits. A cross section through a single phase of the circuit breaker is shown in fig. 7.

Owing to the limited space available in the station, the design of the breakers required careful consideration in order to reduce as far as possible the distance between the cubicle centres: for this reason tanks are of oval section. Each phase is contained in a separate tank, the three tanks being supported from a common top plate which is bolted to a supporting framework. Each tank has been hydraulically tested for 30 minutes at a pressure of 400 lbs. per sq. in.

Suitable lugs on the tank walls enable them to be raised or lowered by means of a transportable hand operated hoist. The tanks are lined with elephantide and are provided with visual oil gauges.

The solenoid operating mechanism, solenoid contactor and auxiliary switches are all mounted on a steel plate fixed to the supporting framework and to fabricated angle brackets situated between the phases and bolted to the top plate. This con-

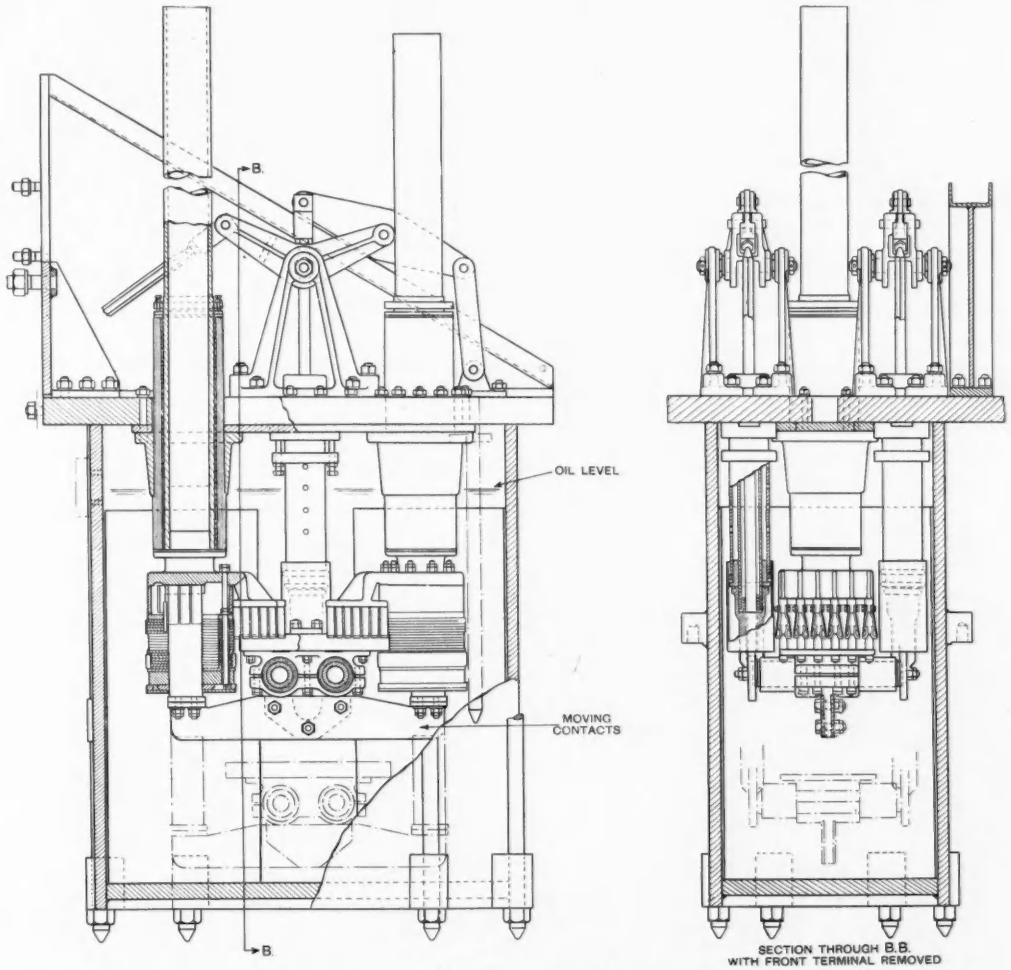


Fig. 7.—Sectional diagram of a 6,600 volt, 1,000,000 kVA oil circuit breaker, showing arc control pots and main contacts.

struction provides a very rigid assembly and prevents the transmission of dynamic stresses to the cubicle framework.

The tubular copper terminal stems are led through the breaker top plate by means of bakelite bonded paper bushings fitted with shrunk-on flanges, and support cast copper contact blocks which carry the fixed main contact fingers, the side-blast arc control pots and the fixed arcing contacts.

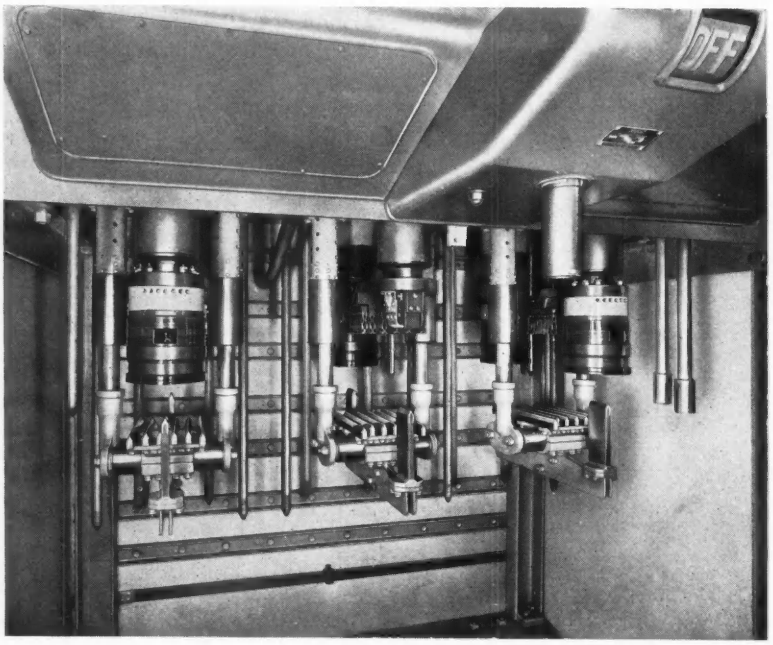


Fig. 8.—Arc control pots and main contacts fitted to a 1,000,000 kVA oil circuit breaker.

The main moving contact bars are of wedge section and are carried by two horizontal bakelite tubes which are reinforced internally by means of duralumin tubes. The ends of the tubes are clamped to steel castings which in turn are connected by steel rods to the operating linkwork. The moving arcing contacts are underslung from the horizontal bakelite tubes. Steel tubes are attached to the steel castings previously mentioned and form the moving members of the oil dashpots employed to cushion the opening stroke of the circuit breaker. A number of small holes in the lower end of the outer tube of the dashpot may be filled by screwed plugs so that the cushioning effect may be adjusted.

The arc control pots, figs. 7 and 8, consist of a tubular chamber surrounding the fixed arc contacts. A stack of special horn fibre plates is clamped to the chamber and slots are provided in the plates which are uncovered by the moving contact as it moves downwards. The fixed arcing contacts are mounted in pairs and are of copper faced with a special heavy alloy developed by the G.E.C. for this purpose. The moving arcing contacts are constructed throughout from steel and are also faced with similar heavy alloy.

In order to reduce the burning of the main arcing contacts, auxiliary arcing contacts are mounted a short distance below them. These do not come into physical contact with the moving contact, but as the tip of the latter passes them, the arc is transferred from the main to the auxiliary contacts. The auxiliary contacts serve also as backing stops for the main arcing contacts and prevent the latter from being forced backwards by the pressure due to the arc.

The steel operating linkwork gives a vertical lift and operates in special non-rusting bearings which, where necessary, are self-lubricating. Twin pull rods from each phase are connected to the main cross shaft of the solenoid mechanism. This shaft is supported by brackets fitted with ball bearings, and a toggle device actuated by the solenoid coil provides the necessary torque to close the breaker. A special feature of this design is the method of absorbing the shock of the moving contacts on closing. An oil dash pot situated immediately above the solenoid plunger comes into operation during the last part of the closing stroke. Immediately the breaker opens, strong springs act upon the dash pot and reset it ready for the next closing operation.

In emergency, the breaker may be closed by a portable hand operated hydraulic ram which when plugged into a receptacle provided beneath the solenoid mechanism enables the solenoid plunger to be lifted and the breaker closed.

CONTROL BOARD.

The control panels are placed in a control room which is situated on the lower floor of the switch house adjacent to the engine room. For the majority of the circuits, existing panels and equipment, which originally belonged to the 500,000 kVA gear are utilised. Complete new panels and equipment, however, are provided for the alternator and voltage control equipments.

The control board is surmounted by a mimic indicator panel incorporating double impulse type semaphores, and is equipped with control switches for operating the circuit breakers as well as the usual indicating lamps and synchronising plug receptacles. The alternator panel carries an ammeter, indicating

wattmeter and power factor meter as well as an integrating watt-hour meter. The other instruments for the alternator include a 3-pole circulating current protective relay, a negative phase sequence relay and a tripping relay. Switches for the governor motor control circuit and for operating the neutral earthing switch and turbine stop valve are also provided.

The protective gear included on each Grid transformer panel consists of a triple pole overload relay, a single pole relay for restricted earth leakage protection and a single pole back-up leakage relay.

For controlling the voltage of the alternator an automatic voltage regulator of the rheostatic type is provided, the motor driven field regulator for this being mounted behind the voltage control panel.

In the event of the failure of the motor of this regulator, emergency hand operating gear is provided mounted on a pedestal immediately in front of the control panel and on the same pedestal, a single pole exciter field breaking switch is also mounted.

The neutral point of the alternator is connected through a single pole electrically operated oil switch to a busbar on to which the neutrals of the five existing machines are also connected through oil switches. This busbar is coupled to two neutral earthing resistances in parallel and a current transformer is mounted in the bar to operate an alarm relay in the event of an excessive earth current flowing. The earthing resistances themselves are of the liquid type for outdoor mounting, the resistance of each being 2·2 ohms. They are each capable of carrying 1,750 amperes for 30 seconds.

The auxiliary multicore cables run along the wall at the rear of the control panels, through the wall and along the outside of the control room in the passage way in front of the instrument transformers and feeder isolator cubicles. The cables are supported in mild steel racks and tap off to the main terminal boards which are located at the top inside the cubicles.

SHORT CIRCUIT TESTS.

The whole of the equipment supplied was subjected to type tests in the High Power Testing Laboratory at Witton. The object of these tests was to demonstrate that the circuit breakers comply with the provisions of British Standard Specification No. 116, Part II, 1937. In addition, the tests were to show that the busbar structure, isolating switches, current transformers and main connections are all capable of withstanding the mechanical and thermal stresses imposed by the maximum short circuit current which they may have to carry.

RATING.

The rating of the gear is as follows :—

Rated service voltage	6·6 kV
Rated normal current	3,000 amps. and 4,000 amps.
Rated frequency	50 cycles per second
Rated breaking capacity.. ..	1,000,000 kVA
Rated symmetrical breaking current	88,000 amps.
Rated asymmetrical making current	220,000 amps.
Rated operating duty	break—3 mins. make break—3 mins.—make break.

It is probable that 1,000,000 kVA is the maximum breaking capacity for which it is economically practicable to construct 6·6 kV switchgear. The peak making current of 220,000 amperes imposes very large mechanical stresses upon the whole structure of the gear, and particularly upon the circuit breaker contacts, which, in addition, must be capable of withstanding the intense heat and burning caused by the heavy current arcs. In fact, for such a large breaking capacity at 6·6 kV, the design of the breaker to withstand the electrodynamic forces on short circuit is more difficult than that of the arc control device.

ARRANGEMENT OF CIRCUIT BREAKER FOR TEST.

For the short circuit tests a circuit breaker and

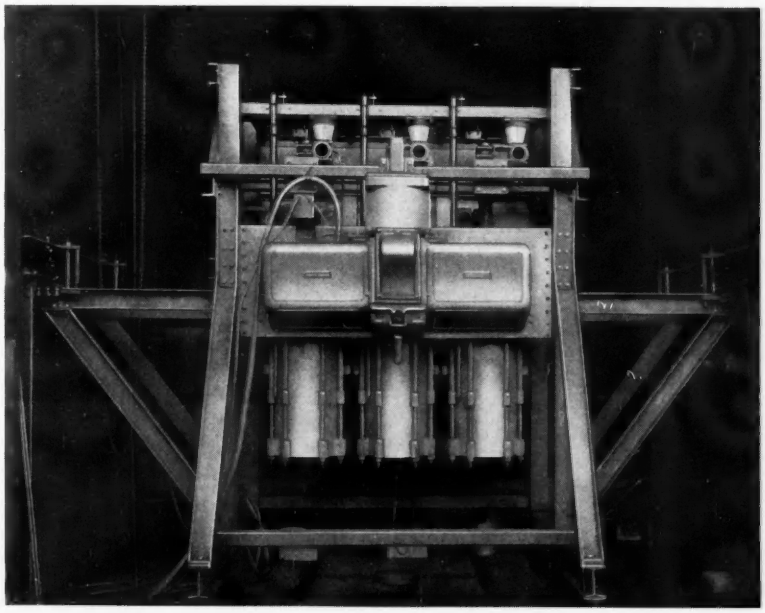


Fig. 9.—One of the oil circuit breakers erected for test at the Witton High Power Testing Laboratory.

three current transformers were mounted upon a test framework (fig. 9) resembling as closely as possible the steelwork of the cubicle in which they were to be mounted on site; the connections between the breaker and the current transformers, and between the current transformers and the test bay terminals, were made by means of copper tubes exactly similar to those used in the busbars and main connections,

TABLE I.

Tests carried out on a 6,600 volt, 1,000,000 kVA Oil Circuit Breaker for Norwich Corporation.

Test No.	Operation and Time Interval	Applied Voltage kV.	Peak Making Current kA.	Breaking Current		Recovery Voltage		Arc Duration Loops in Phase: R. W. B.	Physical Behaviour and Condition After Test
				Symmetrical kA. Average	% D.C. Component Average	kV. Average Between Phases	% Average Between Phases		
TEST DUTY No. 1. AT 10% OF THE RATED SYMMETRICAL BREAKING CAPACITY. BREAKER FITTED WITH NEW ARC CONTACTS AND FILLED TO NORMAL LEVEL WITH CLEAN OIL. BREAKER TESTED THREE PHASE.									
833A	Break 3 Minutes	6·6	—	9·2	6·4	6·55	99	6 7 6	No emission of flame or oil. Very slight emission of smoke from vent pipe. No internal examination.
833B	Break 3 Minutes	6·6	—	9·15	6·7	6·55	99	6 6 6	
833C	Break	6·6	—	9·1	6·0	6·57	99·5	6 6 6	
TEST DUTY No. 2. AT 30% OF THE RATED SYMMETRICAL BREAKING CAPACITY. BREAKER EXACTLY AS AT END OF DUTY CYCLE No. 1. BREAKER TESTED THREE PHASE.									
834A	Break 3 Minutes	6·6	—	28	4·6	6·3	95·3	4 3 3	No emission of flame or oil. Very slight smoke and oil from vent pipe. Arcing contacts slightly burnt. Oil loss negligible.
834B	Break 3 Minutes	6·6	—	28·3	4·5	6·43	97·4	4 3 4	
834C	Break	6·6	—	28·2	6·2	6·27	95	3 3 4	
TEST DUTY No. 3. AT 60% OF THE RATED SYMMETRICAL BREAKING CAPACITY. BREAKER EXACTLY AS AT END OF DUTY CYCLE No. 2. BREAKER TESTED SINGLE PHASE.									
835A	Break 3 Minutes	5·7	—	57·7	3·7	Equiv. 6·9	105·2	2	No emission of flame or oil. Slight smoke from vent pipe. Oil loss negligible. Arc contacts slightly more burnt.
835B	Break 3 Minutes	5·7	—	57·3	8·7	Equiv. 7·0	106·2	1	
835C	Break	5·7	—	58·6	0	Equiv. 7·06	107·1	2	
TEST DUTY No. 4a. AT 100 % OF THE RATED MAKING CAPACITY. BREAKER FITTED WITH NEW ARCING CONTACTS AND FILLED WITH OIL TO NORMAL LEVEL. BREAKER TESTED THREE PHASE.									
828A	Make 3 minutes	4·7	190 107 189	—	—	—	—	—	No emission of flame, slight emission of oil by vent pipe. Contacts moderately burnt. Breaker opened and closed easily after test.
828B	Make	4·7	225 185 159	—	—	—	—	—	
REPEAT OF TEST DUTY No. 4a. BREAKER FITTED WITH NEW ARCING CONTACTS AND FILLED WITH OIL TO NORMAL LEVEL. BREAKER TESTED THREE PHASE.									
837A	Make 3 Minutes	4·7	168 212 266	—	—	—	—	—	No external evidence of operation. Arcing contacts moderately burnt. Breaker opened and closed easily after test.
837B	Make	4·7	108 174 146	—	—	—	—	—	
TEST DUTY No. 4b. AT 100% OF THE RATED SYMMETRICAL BREAKING CAPACITY. BREAKER FITTED WITH NEW ARC CONTACTS AND TESTED SINGLE PHASE.									
829A	Break 3 Minutes	5·7	—	82·0	45·7	Equiv. 7·35	111·6	1	No emission of oil or smoke. No external evidence of operation. Arcing contacts moderately burnt.
829B	Break 3 Minutes	5·7	—	80·8	10·5	Equiv. 7·45	112·5	1	
829C	Break	5·7	—	81·5	5·2	Equiv. 7·6	115·0	1	
TEST DUTY No. 5. AT 100% OF THE RATED ASYMMETRICAL BREAKING CAPACITY. BREAKER FITTED WITH NEW ARC CONTACTS AND TESTED SINGLE PHASE.									
836A	Break 3 Minutes	5·7	—	87·2	62·1	Equiv. 7·7	116·8	1	No emission of smoke or oil. Slight smoke from vent pipe. Arcing contacts moderately burnt.
836B	Break 3 Minutes	5·7	—	85·8	18·2	Equiv. 7·7	116·8	2	
836C	Break	5·7	—	86·1	31·1	Equiv. 7·7	116·8	1	

supported by the standard porcelain insulators as used in the actual cubicles.

A second test framework was made up containing a three-phase set of isolating switches and connections similar to those between the isolating switches and the busbars.

DESCRIPTION OF TESTS.

During the course of the preliminary and official tests the breaker performed nine breaking operations at 10 per cent, ten breaking operations at 30 per cent, ten breaking operations at 60 per cent and thirteen operations at 100 per cent of its rated breaking capacity and four operations at 100 per cent of its rated making capacity. The testing was thus extremely rigorous. A selection of the results of these tests is given in Table 1 and typical oscillograms in figs. 10 and 11.

The circuit breaker was subjected to standard type test duties Nos. 1, 2, 3, 4a, 4b and 5 in clause 98 of British Standard Specification No. 116, 1937, Part II. Test duties Nos. 4a and 4b were substituted for Test Duty No. 4 owing to the impossibility of obtaining the correct values of making and breaking current in the same test duty.

The three-phase tests were made in accordance with the standard specification, with one side of the breaker earthed and the neutral of the test alternator insulated from earth. These conditions give rise to the most severe duty upon the breaker, as the recovery voltage upon the first phase to clear is 1·5 times the normal voltage between neutral and line.

Test duties Nos. 1 and 2 at 10 per cent and 30 per cent of the rated symmetrical breaking capacity respectively were made upon all three phases of the circuit breaker. The applied voltage was 6·6 kV between lines and the recovery voltage was between 95 per cent and 99 per cent of the rated service voltage and thus in accordance with the specification. The operation of the breaker in both cases was very quiet, there being practically no external evidence of the breaker having opened.

Owing to limitations of the capacity of the test plant, it was not possible to perform Test Duties Nos. 3, 4b and 5 upon all three phases of the breaker simultaneously. These tests were therefore again made in accordance with the specification upon the centre phase of the breaker only, the applied voltage being 5·7 kV.

The recovery voltage in these tests was therefore equivalent to that in the first phase to clear on a three phase test and was actually over 100 per cent. This was due to the effect of the super-excitation of the test alternator, which, by strongly increasing the excitation during short circuit, prevents the decay of the short circuit current, and causes the alternator voltage to rise slightly during the test.

Test Duty No. 4a at 100 per cent of the rated making capacity of the breaker was conducted upon all three phases of the breaker, in order to test the mechanism of the individual phases and the solenoid operating gear and connections. In order to obtain the correct value of current, it was necessary to reduce the applied voltage to 4·7 kV as indicated in the table.

The first Test Duty No. 828a and b resulted in the rated peak making current being attained in the second operation of the duty cycle only, when a maximum peak value of 225 kA was measured. The Test Duty was accordingly repeated, and on the first operation of Test No. 837a, a peak making current of 266,000 amperes, that is 21 per cent in excess of the rated value, was attained. There was no visible effect at all on any part of the gear, no loosening of any of the connections or other parts

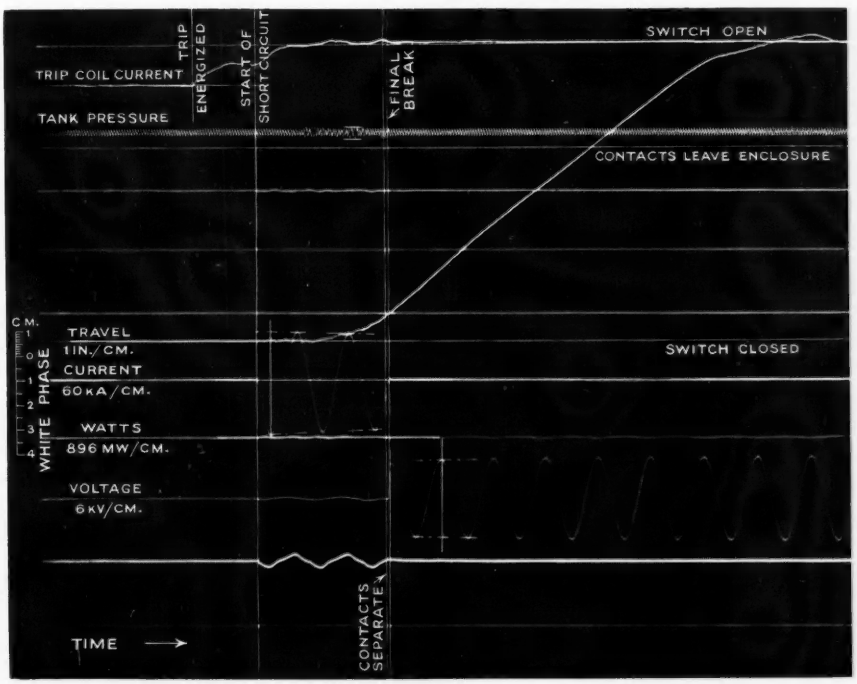


Fig. 10.—Oscillograms of Test No. 829C on 6·6 kV, 1,000,000 kVA oil circuit breaker.

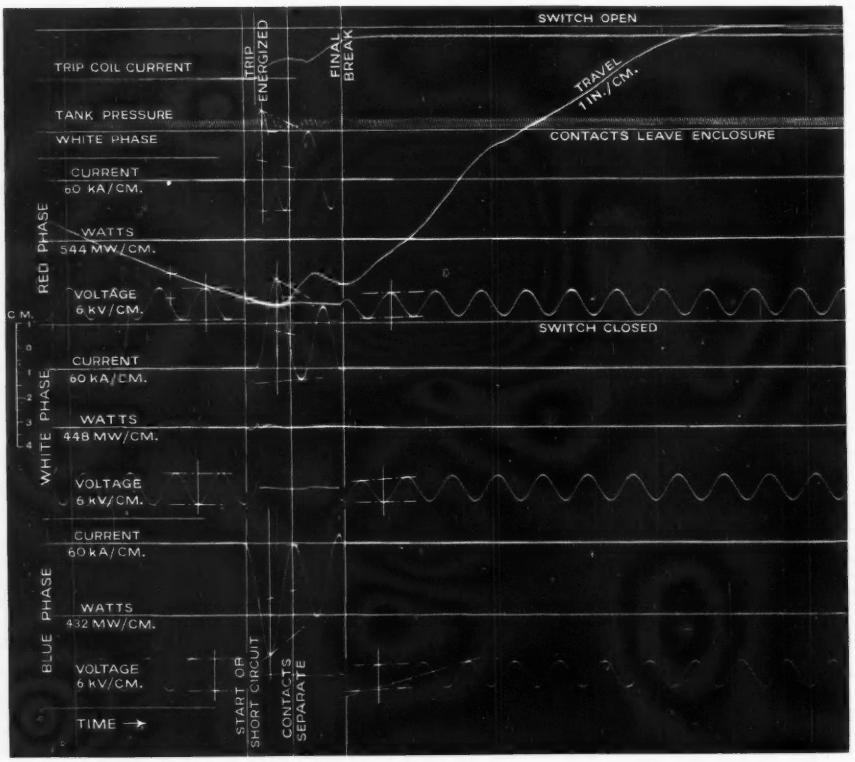


Fig. 11.—Oscillograms of Test No. 837A on 6·6 kV, 1,000,000 kVA oil circuit breaker.

of the circuit breaker could be detected, and the burning of the arcing contacts upon which the current was made, was quite moderate.

Examination of Table 1 shows that the arc control device, although simple, is efficient. The duration of arcing at 60 per cent and 100 per cent of the full breaking capacity does not exceed two half cycles, and in a large proportion of the tests did not exceed one half cycle. The duration of arcing was naturally longer at 30 per cent and 10 per cent of the full breaking capacity, but did not exceed 4 and 7 half cycles respectively.

As anticipated, the use of an efficient arc control device resulted in the tank pressure during the breaking operation being very low. In none of the tests given in Table 1 did the pressure exceed 100 lbs. per square inch. As the tanks were subjected to a static pressure test at 400 lbs. per sq. in., it will be seen that the factor of safety is very large.

TESTS UPON ISOLATING SWITCHES AND CONNECTIONS.

As mentioned above, a three-phase set of isolating switches, together with the appropriate connections was mounted on a test framework resembling as closely as possible the metal work of the actual cubicle, and subjected to a series of short circuit tests.

The current passed through the assembly was increased progressively until a peak value of 239,000 amps. was reached, the total duration of the passage of the current being 18-half-cycles. The passage of this current through the isolating switch and connections had no visible effect whatever, and produced no marking of the contacts of the switch, nor movement of the conductors. The amount of heating produced was also negligible.

In conclusion, acknowledgment is due to V. Alexander Pask, Esq., M.I.E.E., A.M.I.Mech.E., City Electrical Engineer to the Norwich Corporation Electricity Department for permission to publish the information and illustrations contained in this article.

The Design of Domestic Electric Cookers.

PART II.

By O. W. HUMPHREYS, B.Sc.
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This is the second and concluding part of a paper read before the Institution of Electrical Engineers on the 20th January, 1938, Part I. of which was published in the February issue (Vol. IX., No. 1) of the G.E.C. Journal.

In this section, the author deals with grillers and boiling plates. The history of the development of boiling plates is briefly reviewed and the relative advantages and disadvantages of the various methods of construction employed in this country are discussed.

GRILLERS AND GRILLER-BOILERS.

THE great majority of cookers sold in this country include in their hob equipment a fitment commonly known as a "griller-boiler" which is designed to serve the dual functions of griller and boiling-plate. A few models have a separate griller mounted below the hob, and in one or two instances the American practice of using the top element in a top-and-bottom-heated oven for grilling is followed.

In the most commonly employed form of griller-boiler, heating coils are mounted in porcelain formers, so designed that radiation in both the downward and upward directions is as little obstructed as possible, beneath a top plate of cast iron, or heat-resisting alloy steel. Very careful designing is necessary to ensure adequate strength for the formers. A wire guard protects the element and a reflector is provided to concentrate the heat on to the metal top when grilling is not in progress.

The grilling performance of these units is in general very good, but their speed and efficiency as boiling plates is low; they are not to be recommended for boiling unless grilling is carried out at the same time, in which circumstances the overall "efficiency" is very high. Some manufacturers supply kettles of such a shape that they just cover the surface of the griller-boiler, and if these are used a considerably improved performance is obtained.

The relatively large area of the griller-boiler renders it very suitable for simmering a number of utensils simultaneously, and the low density of loading, as compared with that of most boiling-plates, is in this case an advantage.

A second type of griller-boiler, which is more frequently used as a separate unit than as a fitment in cookers, employs a sheathed-wire heating element and no top plate. It is provided with a reflector which can be placed above or below the element when the latter is used for boiling or grilling only. As a grill it is very satisfactory, and its speed and efficiency as a boiling-plate are greater than those of the open-coil metal-topped type. It cannot be used for grilling and boiling simultaneously, however, unless the kettle or saucepan is spaced away from the heating element, which naturally greatly reduces the speed of boiling, for with the vessel in contact with it the element does not reach a sufficiently high temperature for effective grilling. A further disadvantage is that if the contents of the vessel boil over, they are most likely to fall on to any food which is being grilled.

A possible criticism of griller-boilers in general is that the area which they offer for grilling is rather small, especially for the large cookers. Size is, to some extent, restricted by available hob space, and in that respect the separate griller offers the advantage that it can be designed to extend under the boiling-plates.

BOILING-PLATES.

In no direction has improvement in cooker performance been more rapid than in the case of the boiling-plate. Yet, at least during the last 10 years no revolutionary changes have been made in design. Progress has been due rather to the almost continual detailed improvement of well-established products.

Historical Review.

During the latter part of last and the early part of the present century boiling-plate designers were very active, and it is very interesting to review their proposals in the light of our present-day knowledge.

In 1896 Chambers proposed the use of a resistor embedded in cement (consisting, according to his patent specification, of 2 parts by weight of plaster of paris and 1 part by weight of oxide of iron) in a dished metal top plate. In the following year Schindler and Jenny protected a form of construction in which the resistor was embedded in refractory around which a shell of aluminium, copper, or bronze was cast. At about the same time Archer embedded a crimped resistor in an enamel coating on the inside of a dished metal top, and many boiling-plates of this type were sold.

Of quite a different type were the Prometheus elements which were in commercial production about 1905. Instead of a resistance wire these elements employed a conducting film, made by mixing gold and platinum powder with a suitable flux, painted on to strips of mica, which, with suitable mica insulation, were clamped to the under-sides of steel top plates.

The use of a grooved iron top was first referred to in a patent granted to Teuber in 1905. The heating coils were not embedded, but were secured in enamel-lined grooves by shellac.

The early boiling-plate designers were seriously handicapped by the absence of a really good heat-resisting alloy. Such materials as german silver and eureka had to be pressed into service, and consequently wire temperatures and loadings were very restricted. The development of nickel-chromium alloys had been proceeding concurrently with that of boiling-plates since 1896, when Placet had obtained a patent covering the addition of chromium to metals such as manganese, ferro-nickel, etc., for the purpose of increasing their electrical resistance. Marsh and others carried on the development, and between 1910 and 1913 nickel-chromium alloys gradually came into commercial use.

A considerably increased wire temperature then became possible, and enamel and other embedding materials which had been used hitherto were no longer satisfactory. Solid metal tops continued to be used, but they were heated by wound mica elements clamped to their under-sides.

The new alloys were not, at first very reliable, but they were rapidly improved and after a few years, operating temperatures higher than those for which mica was suitable, became possible. At the time there arose a growing demand for a boiling-plate which would give some visible evidence of its heat-giving capabilities. The combination of these two factors led to the development of various forms of exposed-resistor boiling-plates. The first plates of this type were so prone to damage by spilled liquids that their life was very short. Improvements aimed at facilitating the escape of spilled liquids were introduced, but no form of construction was found which satisfactorily accomplished this so far as viscous liquids were concerned. Open-coil plates were also very subject to mechanical damage and introduced a somewhat serious risk of shock to users who endeavoured to remove a foreign body which had fallen on to the heating coils. In addition it was found that, although the glowing coils gave the appearance of speed, these boiling-plates were not very fast and their efficiency was low.

The popularity of the high-voltage open-coil plates began to wane about 1925, and very soon the reaction against them assumed such proportions that manufacturers had to fit their open-coil plates with sheet-metal covers until such time as new designs could be developed.

The efficiency of these makeshift plates was so low that, in spite of the increase in loading, they were slower than many of the earlier enclosed plates. These temporary expedients were followed, in the natural course of development, by enclosed boiling-plates in which the heating coils were mounted in refractory blocks designed to permit the maximum radiation from the coil to plain or grooved boiling-plate tops. One example of this form of construction is still available, but generally speaking it never became very popular, being superseded by the three types of embedded-resistor boiling-plate and the low-voltage exposed-resistor plate which are now in common use and are described below.

Present-Day Boiling-Plates.

Embedded-resistor Plates.

(i) *Cast-iron top.*—This type of boiling-plate, in which the heating coil is embedded in refractory cement in grooves in a cast-iron top, may be regarded as a modern adaptation of Teuber's form of construction. In its present form it was first developed in Switzerland, and was gradually introduced into this country during 1925 and 1926. Subsequently very large quantities were imported. Although very massive, and slow and inefficient as compared with modern products, these plates marked a real advance so far as performance, life, and durability were concerned. British manufacturers soon became interested. New methods of production were developed which enabled refractory cements having better insulating properties to be used, castings were lightened, loadings raised, and performance generally was gradually improved. The course of this progress can be followed from figures given in Table 1 for typical plates of this type.

TABLE 1.

CAST-IRON BOILING-PLATES.

Date	Diameter in.	Loading watts	Boiling Time* min.	Efficiency per cent.	Insulation Resistance† ohms.
1925	8½	1 200	20	38	
1929	8	1 600	12.6	49	3 000
1929	8	1 600	10.5	61	23 000
1932	8	1 800	9.4	60	9 000
1934	8	1 800	9.4	60	250 000
1935	8	2 250	8.0	56	60 000

* Three pints of water in flat-bottomed vessel, 85 deg. C. temperature-rise.
† At maximum temperature with no vessel.

(ii) *Sheathed wire.*—The earliest forms of heating element consisting of a coiled resistor embedded in refractory inside a metal tube were produced some 20 years ago in America. Alternative methods of production were developed later in Sweden, and still more recently in this country. The earlier methods have been continually improved to meet modern conditions, and this type of plate

is now in regular production in this country by three or four distinct methods.

(iii) *Sheet metal.*—The third type, which also originated in America, employed at first a light dished top, of alloy steel, in which the resistor was embedded in cement. This construction was found to be prone to distortion. To overcome this drawback the top was first bonded to a metal back-plate by means of metal eyelets, and later divided into two separate, relatively narrow, rings. It is in the latter form that this boiling-plate is now available.

Exposed-resistor Plates.

The only type of exposed-resistor boiling-plate commonly fitted to British cookers employs a short resistor of large cross-sectional area, which is supplied with energy at a voltage of about 10 volts from a transformer built into the cooker.

For the sake of brevity the above types will, in the remainder of the paper, be referred to as: (1) cast-iron embedded, (2) sheathed-wire, (3) sheet-metal embedded, (4) low-voltage exposed-resistor.

Factors Affecting Performance.

The relative importance of the chief properties of a boiling-plate, namely life, speed of boiling, efficiency, and insulation resistance, is largely a matter of opinion, but most people would probably place them in the above order. It is most important, however, that a proper sense of proportion should be maintained and that unwarranted sacrifices of other properties should not be made in order to obtain exceptionally good performance from one particular point of view. The factors on which these properties depend will now be very briefly outlined.

A boiling-plate consists essentially of a resistor and mechanical component, which serves as a support for both the resistor and the vessel. For convenience, the two components will be referred to as the resistor and the support, but the latter component will, in the majority of cases be a complex one.

Life.

The useful life of a boiling-plate is ended when it no longer gives satisfactory service to its user, whether the cause be the failure of the resistor or the fracture or serious distortion of the support.

What is commonly referred to as a "normal failure" of the resistor occurs as a result of oxidation, which leads to the development of a hot spot where fracture eventually occurs. The rate of oxidation depends on the composition, temperature, and diameter of the wire, the term "composition" being broadly intended to include the manufacturing process.

Resistance alloys have been markedly improved during recent years. The basic composition of nickel-chromium alloys is still 80 per cent. Ni and 20 per cent. Cr, but, in consequence of the addition of minute amounts of other substances and improvements in manufacturing technique, the life of the best alloys under test conditions approximating to those of normal use is now 6 or 7 times as long as it was 3 or 4 years ago. Alternatively, the same life can be obtained at a temperature at least 100 deg. C. higher than previously. Progress has also been made with the development of the aluminium-containing alloys, which are now comparable with the best commercial nickel-chromium alloys so far as resistance to oxidation is concerned.

Failure of the resistor may also result from chemical or electrolytic action between it and some part of the support, from contact with an earthed part of the support, or from fracturing of the joint with the heavy end leads.

Possible causes of failure of the support will be considered in connection with the individual types of boiling-plate.

Speed of Boiling.

Speed of boiling is directly proportional to the product of efficiency and loading. Efficiency is considered below. The upper limit of loading may be determined by either the resistor or the support, according to the type of construction employed. In the cast-iron embedded plate, for example, the determining factor is casting temperature, whereas in the low-voltage exposed-resistor and sheathed-wire plates it is wire temperature. As increasingly higher wire temperatures become permissible the limit for embedded plates may be set by the insulating properties of the embedding cement.

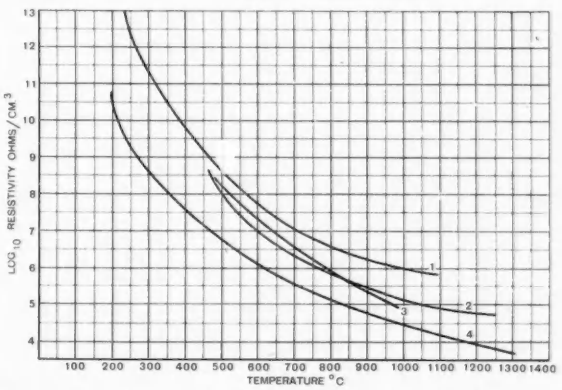

Fig. 8.—Variation of electrical resistivity of refractories with temperature.

1. Curve for fused silica, compiled from data given by A. CAMPBELL. (*Proceedings of the Physical Society*, 1913, vol. 25, p. 336) and by F. HORTON (*Philosophical Magazine*, 1906, vol. 11, p. 505).
2. Magnesia (F. HORTON: *Philosophical Magazine*, 1906, vol. 11, 505).
3. 90% Zircon Sand + 10% Grosalmerode Clay.
4. Silimanite.

Efficiency.

The thermal efficiency of a boiling-plate is defined as the ratio of the heat absorbed by the liquid heated, to the heat equivalent of the energy

dissipated in the boiling-plate, multiplied by 100. Most of the heat which is not usefully employed is either absorbed by the plate itself or radiated from its under-surface and edges. The actual efficiency obtained must obviously depend to a large extent on the type of vessel used. So far as the boiling-plate itself is concerned the important quantities are its heat capacity, its mean temperature at the conclusion of the boiling operation, and the temperature of its exposed surfaces.

Insulation Resistance.

The least satisfactory aspect of most modern boiling-plates is their insulation resistance when hot. The controlling factors are the composition and temperature of the refractory in which the element is embedded. Fig. 8 indicates the very rapid decrease in the electrical resistance of refractory insulating materials with increasing temperature. Very great improvement has been effected by the use of the new materials. For example, the insulation resistance of 2,250-watt 8in. diameter cast-iron embedded plates under steady-state conditions with no vessel may now be as high as 60,000 ohms, whereas less than 10 years ago values of 10,000 ohms, or even less, with a loading of only 1,600 watts, were common. No manufacturer is really satisfied with this advance, however, and research for materials having still better insulating properties is continuing.

Appraisal of Different Methods of Construction.

Exposed-resistor Method.

(i) *High-voltage type.*—This form of construction possesses the advantages of psychological appeal, very high insulation resistance, and low replacement cost, but these are more than offset by danger to the user, proneness of the resistor to injury, low efficiency, and the fact that the wire temperature for a given loading is higher than in the case of an embedded plate of similar dimensions. This latter disadvantage arises from the well-known fact that for a given energy dissipation the temperature-rise in a wire is less if the wire be lagged than it if be bare. This phenomenon can be readily demonstrated by placing in circuit a cast-iron boiling-plate, having the refractory completely removed from about 1in. of the groove, and partially removed, in such a manner as just to expose the outside of the coil, from an adjacent part of the groove. When conditions become steady, it is obvious from visual inspection that the completely exposed part of the coil is considerably hotter than the part which is embedded.

The wire temperature is still further increased during a boiling operation since the transmission of heat is almost entirely by radiation, and the surface of the vessel is at a higher temperature than the surroundings to which the element radiates when uncovered. If a vessel with a highly reflecting base is used the increase in temperature is very large.

(ii) *Low-voltage type.*—The low-voltage boiling-plate possesses all the advantages which are associated with the use of an exposed resistor, and at the same time is largely free from the disadvantages which are inherent in the high-voltage type. Danger of shock is entirely removed, the very robust resistor is not readily susceptible to damage, and on account of its large cross-sectional area it is able to withstand temperatures considerably in excess of those which are permissible with any other boiling-plate.

From the point of view of psychological appeal, and ability to create an impression of speed, the low-voltage plate is pre-eminent.

Its principal disadvantages are that its initial cost, including the transformer, is substantially higher than that of any other type of plate, and that, in common with all plates which depend mainly on radiation for heat transfer, its efficiency is low, especially when used with aluminium or other utensils having bright bases.

Cast-iron Embedded Method.

Apart from the general advantages associated with the embedded construction, the chief merit of cast-iron type is that the resistor is so definitely

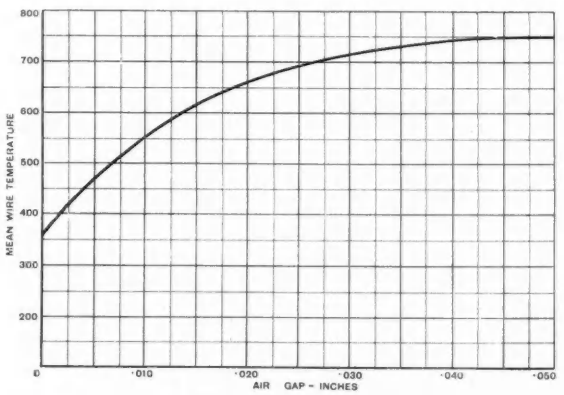

Fig. 9.—Relation between air-gap and mean wire temperature for 8in. cast-iron boiling-plate; loading 1,800 watts.

located along its whole length that the clearance between adjacent turns can be very small, and in consequence a very long coil, of large-diameter wire, can be accommodated. In an 8in. diameter boiling-plate, for example, each coil may be as long as 60in. Consequently the wire temperature is exceptionally low: in an 8in. diameter 2,250-watt plate it may be as low as 800° C. under steady-state conditions with no vessel, and, so far as oxidation of the resistor is concerned, life is practically unlimited.

Under normal-use conditions the wire temperature is still lower since the heat transfer to the vessel

is mainly by conduction, either directly from metal to metal, or through the small air-gap between the boiling-plate and the vessel. The actual temperature depends on the width of this gap. The relation between mean wire temperature and gap for an 1,800-watt boiling-plate is shown in fig. 9. With a commercial machined-bottom aluminium or cast-iron vessel, the mean gap is of the order of 0.005in., and the wire temperature is approximately 270 deg. C. lower than when no vessel is in use. The temperature of the casting depends in a similar way on the

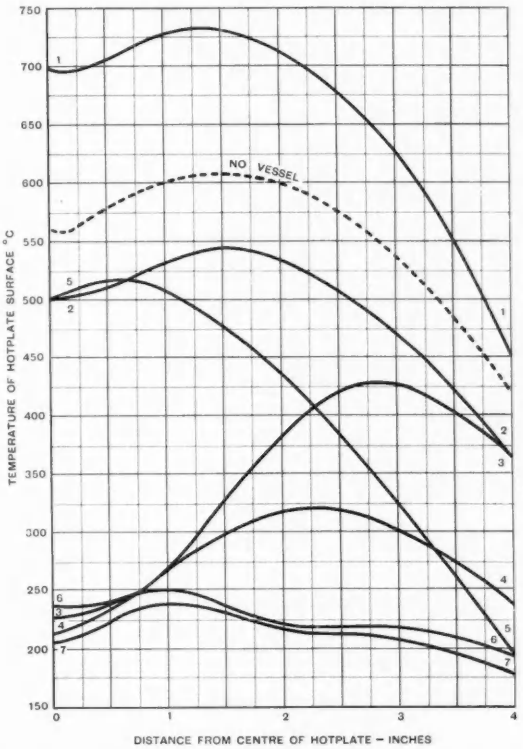

Fig. 10.—Variation of casting temperature with different vessels using 8in. diameter boiling-plate; loading 1,800 watts.

1. Kettle with re-entrant bottom.
2. Enamelled iron pan.
3. Pressed aluminium pan with convex bottom.
4. Ordinary kettle with copper bottom.
5. Pressed aluminium pan with concave bottom.
6. and 7. Aluminium pans with machined bottoms.

flatness of the bottom of the cooking utensil. It will be seen from fig. 10 that with a machined-bottom vessel the maximum casting temperature is only 250° C., and with any good-quality commercial vessel it is lower than when the surface of the boiling-plate is uncovered. With so low a temperature-rise the losses by absorption in, and radiation from, the boiling-plate are low, and its efficiency is therefore high in spite of its relatively large heat-capacity.

Under life-test conditions[4] no cracking or serious distortion occurs provided good-quality properly-annealed castings are used, and it follows that no such trouble is to be anticipated in normal use with good-quality commercial utensils. If badly-distorted pans are used, however, the casting may reach a temperature considerably higher than that obtained with no vessel, and cracking may then occur after quite a short period of use.

In some parts of the Continent the use of any but machined-bottomed utensils with cast-iron boiling-plates is practically unknown, and is regarded as abuse. While it is by no means necessary to go as far as this in order to eliminate all risk of cracking, such a course is well justified on the grounds of the resulting improvement in performance and economy of operation.

A discussion of the causes of, and possible methods of eliminating, cracking under severe conditions of use scarcely falls within the scope of the present paper. It may be mentioned, however, that the trouble is frequently aggravated rather than alleviated by the use of heat-resisting-alloy irons, which, on account of their relatively large coefficients of expansion and low thermal conductivities, are subjected to greater stresses in use than arise with straightforward iron castings.

Failure of the resistor may occur through liquids spilled on the top of the plate creeping up the inside of the rim and soaking the refractory. Serious creepage only occurs when the boiling-plate is cold. If the surface of the plate is kept dry, and in particular care is taken not to use an excessive quantity of water for cleaning purposes, no trouble should arise. With a view to eliminating this cause of failure one manufacturer provides a double drip rim in the manner shown in fig. 11.

Corrosion of castings, which in many areas is seldom heard of, but in others is quite serious, is also mainly dependent on conditions of use. Provided the surface of the boiling-plate is kept clean and dry at all times, no corrosion should occur.

Sheet-metal Embedded Method.

Provided a suitable material is chosen for the top, this construction is free from the troubles due to cracking and corrosion to which the casting of the cast-iron embedded plate is prone under severe conditions of use. This advantage is gained, however, at the expense of some increase in wire temperature; firstly, because the construction does not permit of the accommodation of so great a length of wire,

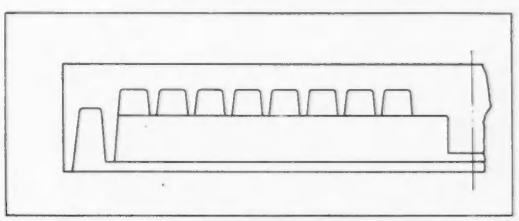

Fig. 11.—Double drip rim casting.

4 See British Standard Specification No. 744–1937.

secondly owing to the absence of the thermally-conducting fins between the turns of the resistor, and thirdly owing to the difficulty of obtaining a really effective and permanent bond between refractory cements and sheet metal. With the continued improvement in resistance wires, this disadvantage becomes less serious.

The substitution of sheet metal for cast iron results in a substantial reduction in heat capacity.

Sheathed-wire Method.

The main appeal of the sheathed-wire boiling-plate is psychological, and from this point of view it is the nearest mains-voltage equivalent to the low-voltage exposed-resistor plate. Its surface temperature is of necessity very much lower, about 700° C. being a maximum figure, and consequently the density of loading is also lower. Its efficiency, on the other hand, is much higher since the vessel, being in contact with the sheath, receives a considerable amount of heat by direct conduction.

So far as wire temperature and life are concerned, comparison must be made with other types of embedded boiling-plates. When designing the cast-iron and sheet-metal embedded plates, everything possible is done to keep the temperatures of both the top and the wire as low as possible. This cannot be done with the sheathed-wire plate since its surface must operate at red heat if its greatest advantage is to be retained. All that is possible, therefore, is to keep the temperature-difference between the resistor and the sheath as low as possible by the use of the largest-diameter coil that can be accommodated. With present-day resistance wires a thoroughly satisfactory life can be obtained, but wire temperature is very definitely the limiting factor and considerable care in design is still required.

Tubes of nickel, calorized steel, stainless steel, and nickel-chromium have been used from time to time for the sheath. The last-named, which has only recently become available in solid-drawn form, offers complete freedom from oxidation, cracking and corrosion. Its cost, for a given size of plate, is several times that of a casting, and this form of construction is therefore inherently much more expensive than that used in the cast-iron embedded plate.

The problem of liquid creepage arises only at the ends of the elements, and these can be protected either by sealing the ends of the tubes, for which purpose glass is sometimes used, or by shrouding them.

Owing to the high operating temperature the insulation resistance of sheathed-wire plates is considerably lower than that of other embedded types. A typical figure for an 1,800-watt 8in. diameter plate at maximum temperature with its surface uncovered is 40,000 ohms. The corresponding figure for a cast-iron boiling-plate of similar size and loading, employing the same refractory, is about 250,000 ohms. The operating temperature is further increased, and the insulation resistance correspondingly lowered, by the use of vessels having markedly curved or distorted bases, especially if their surfaces are highly reflecting. In extreme cases, such as would lead to rapid cracking of cast-iron plates, breakdown of the insulation may occur.

TABLE 2.

EFFECT OF CURVATURE AND COLOUR OF VESSELS ON BOILING TIME, FOR VARIOUS TYPES OF BOILING-PLATE.

Boiling-plate.		Boiling times for 3 pints of water—using vessels as stated					
Type	Loading	Thin aluminium			Heavy (machined bottom) aluminium		Vitreous-enamelled iron
	watts	Vessel A min.	Vessel B min.	Vessel C min.	Vessel D min.	Vessel E min.	Vessel F min.
Cast-iron embedded	1 800	10.3	11.7	13.9	9.4	9.4	14.2
Sheathed wire	1 500	12.8	12.2	12.7	11.7	11.6	11.1
Low-voltage exposed-resistor	2 250	15.9	14.9	15.1	14.2	12.0	11.5

Vessels.

Some reference has already been made to the effect of the type of cooking utensil on performance, but this question is felt to be of sufficient importance to warrant a few further words.

Table 2 gives boiling times obtained with 6 commercial vessels on each of 3 boiling-plates of different types. The tests were conducted some years ago, and the loadings are in some cases below present-day values.

The vessels used are described in Table 3. All boiling times given are for 3 pints of water, and the conditions of test were as laid down in Technical Report Ref. Z/S1 of the British Electrical and Allied Industries Research Association[5].

Cast-iron embedded, sheathed-wire, and low-voltage exposed-resistor plates were tested. Examination of the test results shows that the performance of both the cast-iron embedded and the low-voltage exposed-resistor plates is largely affected by the type of vessel used, although in quite different ways. With the cast-iron plate, the shortest boiling time is obtained with the flat-bottomed vessel. The

5. This report was used as the basis for British Standard Specification No. 744—1937.

absorption coefficient of the base has no effect, as is shown by comparison of the results obtained with Vessels D and E, and the boiling time increases with curvature of the vessel, the longest time being obtained with the vitreous-enamelled utensil. The performance of the low-voltage exposed-resistor plate, on the other hand, is very little affected by the curvature of the vessel bottom, but varies considerably with its absorption coefficient; blackening the bottom of Vessel D effects a saving of as much as 2·2 minutes. The shortest time is obtained with the vitreous-enamelled vessel, and the longest with the concave aluminium utensil. The sheathed-wire plate, owing to its ability to adjust the method of heat-transfer to suit prevailing conditions, is much less affected by variation in vessels. With this type of plate also the shortest time is obtained with the vitreous-enamelled vessel, which shows that absorption coefficient is more important than flatness.

Simmering with Embedded Boiling-Plates.

Prior to the introduction of 8in. diameter cast-iron boiling-plates loaded to 2,250 watts, embedded plates were invariably provided with two coils, and controlled by 3-heat series-parallel switches. With coils of equal resistance this enabled full, half, or quarter loadings to be obtained. With a full loading of 1,600 watts the quarter loading was on the high side for simmering. Increasing the full loading to 1,800 watts accentuated the difficulty, and when it was raised to 2,250 watts some means of providing a lower loading than 562 watts became essential. Two methods have been adopted. The first is to provide an external resistance which can be connected in series with the boiling-plate elements to give an additional extra-low loading. The second is to employ three coils of equal resistance in the boiling-plate itself, and to control them in such a way that one coil can be used alone, two or three coils can be connected in parallel, or the three can be employed in series. Either arrangement requires a special 5-position switch, and the loadings which are available are as follows: Two-coil plate with external resistance, 2,250 watts, 1,125 watts, 562 watts, 250 watts; 3-coil plate, 2,250 watts, 1,500 watts, 750 watts, 250 watts. The first arrangement has the advantages that the third (normal "low") loading of 562 watts is more convenient and economical in use than the corresponding loading of 750 watts obtained with the 3-coil plates, and that standard plates are used. The latter advantage appears to the author to be of very real value since it greatly simplifies replacement and the substitution of 4-heat plates for 3-heat plates on existing cookers. The second arrangement has the advantages that no external resistance has to be provided and that no energy is wasted in such a resistance when the lowest loading is employed.

TABLE 3.

Vessel	Type	Base	Maximum distance between base of vessel and boiling-plate in.
A	Thin pressed aluminium	Concave	$\frac{1}{50}$
B	do.	Convex (irregular)	$\frac{1}{50}$
C	do.	Convex (regular)	$\frac{1}{50}$
D	Heavy aluminium	Machined flat	—
E	do.	Painted black	—
F	Vitreous-enamelled iron	Concave	$\frac{1}{16}$

The external resistance gives a free choice of the value of the minimum loading, while with the 3-coil plate this is determined by the resistances of the coils.

As to the precise meaning of the term "simmering," there appears to be some difference of opinion. There is no doubt, however, that for certain cooking operations it is very desirable to be able to maintain a temperature between 180° F. and 190° F. (82·2° C. and 87·7° C.) for long periods and that for other purposes an energy input slightly higher than that required just to maintain boiling is necessary. There also appear to be certain other operations for which a temperature between 200° F. and 210° F. (93·3° C. and 98·8° C.) is ideal.

Clearly no one loading can allow all these requirements to be met with the same area of contact between vessel and boiling-plate, especially with the additional complications of tolerances on loadings and supply voltage and variations between vessels. Provided, however, that the loading is not seriously excessive the rate of heat-transfer can be very critically adjusted by varying the area of contact. So far as the value adopted for the extra-low loading is concerned it is difficult to determine the best compromise by laboratory experiments, and experience will have to be taken as the final criterion. The limited experience so far available appears to indicate that a loading somewhat lower than the present 250 watts might be more generally useful.

ACKNOWLEDGMENTS.

The author desires to tender his thanks to the Rheostatic Co., Ltd., for kindly placing at his disposal the curves from which those reproduced in figs. 4–7 were selected, relating to the thermostatic control of ovens; also to Messrs. Belling and Co., Ltd.; British National Electrics, Ltd.; Elexcel, Ltd.; Falk, Stadelman, and Co., Ltd.; Falkirk Iron Co., Ltd.; Hotpoint Electric Appliances Co., Ltd.; Jackson Electric Stove Co., Ltd.; Moffat Ltd.; Siemens Electric Lamps and Supplies, Ltd.; and Simplex Electric Co., Ltd.; for supplying information concerning their current products.

The Concentration of Minerals by Flotation.

PART 1.

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THE mineral-concentrating process known as *flotation* is more widely used than any other for extracting base-metal minerals from the ores in which they occur. It depends for its action on the fact that the surfaces of the minerals can be rendered what is, in effect, greasy by contact with a solution of certain chemical reagents in water. In this state the minerals can be floated on a water-surface in much the same way as a greased needle, and they will also stick to the surface of an air-bubble in water. The rock-forming minerals of an ore, on the other hand, are not affected by the reagents and cannot be floated. If, then, an ore be ground fine enough to release the valuable minerals from the rock-forming constituents, or *gangue*, and be stirred up in water with the necessary reagents, the latter operation being performed in a tank with a pipe or pipes in the bottom through which is blown a continuous shower of minute air-bubbles, the particles of base-metal mineral will attach themselves to the rising bubbles as they come in contact with them, and will be carried up to the surface, where they will collect as a mineral-laden froth which can be skimmed off as fast as it forms. The particles of gangue will not stick to the bubbles and will remain suspended in the water. This method of separating, or *concentrating*, the valuable minerals from the worthless gangue is termed flotation.

Flotation is a comparatively modern process. Up to 20 years ago, the method generally employed for recovering the valuable minerals was what is termed *gravity concentration*, which depends for its action on the fact that the constituents of an ore are of different densities, the minerals of the base-metals being of considerably higher specific gravity than the rock-forming constituents. The different rates of fall in water of the various minerals under appropriate conditions enable them to be separated. As a general rule, gravity concentration is not efficient when the particles of mineral are less than 100 mesh (B.S.I. Specification) in size; that is, when they will pass through a screen with 0·14 mm. square holes. Consequently, the process is not very effective for ores which have to be reduced to 30 or 40 mesh in size in order to release the valuable minerals, because it is not possible to break down an ore to this size on a commercial scale without producing a large proportion of material that is finer than 100 mesh.

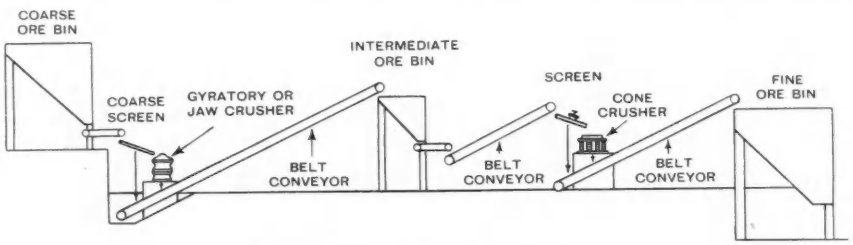


Fig. 1.—Layout of crushing section.

The flotation process, which is the subject of this article, was developed in the first instance to save the fine mineral which was going to waste in gravity concentration plants. It was at first employed mainly for the recovery of copper, lead, and zinc minerals, but its use has since been extended to include a much larger range. The process proved so efficient that it has now become established as the normal method of treating certain types of ores, even when the minerals occur in these ores as comparatively large particles. In general, the largest particle recoverable by flotation is 50 mesh or 0·3 mm. in size; there is no limit in the other direction. For this reason it is normally necessary to reduce

the whole of the ore to a maximum size of 50 mesh previous to flotation or to any smaller size that may be required in order to liberate the bulk of the valuable minerals as individual particles.

Ores Suitable for Flotation.

The sulphide minerals of most of the base metals can generally be floated without difficulty. Ores containing chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), chalcocite (Cu_2S), galena (PbS), sphalerite or zinc blende (ZnS), and pyrite (FeS_2) are seldom concentrated by any other method, unless it happens that some of the mineral is so massive as to be readily recoverable by handpicking or by some simple step of gravity concentration preceding flotation. Metallic minerals such as native copper, gold, silver and platinum, are often concentrated by a combined process which includes flotation of the *fines*, or finer portion of the ore. Installations are also in successful operation for the flotation of malachite ($CuCO_3$), cerussite ($PbCO_3$), anglesite ($PbSO_4$), coal, graphite, native sulphur, molybdenite (MoS_2), limestone ($CaCO_3$), phosphate rock (mixed phosphates of calcium), and fluor-spar (CaF_2).

The minerals which have so far proved difficult to float are mainly metallic oxides such as cassiterite (SnO_2), wolframite ($FeO.MnO.WO_4$), chromite ($FeO.Cr_2O_3$), and iron oxides such as haematite and limonite. These are usually smelted direct, though a preliminary step of gravity concentration is sometimes necessary. Such ores, with the exception of those containing tin, are generally of comparatively high grade—some are almost pure as mined—and at present it does not pay to mine low grade deposits. On the other hand, ores of very much lower grade containing suitable sulphide minerals can be profitably concentrated by flotation. Thus, the treatment of ores carrying only 3 per cent of copper is a commonplace operation in many parts of the world and the large low-grade "porphyry" deposits of the United States can be worked at a profit with a copper content of little more than 1 per cent.

General Description of Process.

The process of concentrating the valuable minerals by flotation comprises five steps—*viz.*, (1) crushing, (2) grinding, (3) flotation, (4) filtration of concentrate, (5) disposal of tailing.

Crushing.

The ore as mined consists of lumps and fines.

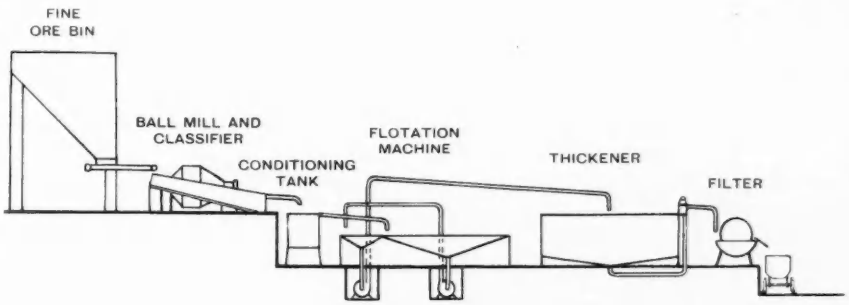


Fig. 2.—Layout of grinding and flotation sections.

The large lumps are first separated on a screen or large sieve and then broken down in a gyratory crusher or a jaw-breaker (see fig. 6) to a maximum size of approximately 3in. cubes. As a certain amount of fine material is made in this operation, the product is mixed with the original fines and passed over a screen with ½in., sometimes ⅝in., square holes. The oversize is fed to a cone crusher (fig. 7), which reduces it to minus ½in. or ⅝in. size, as required, and the crushed product is mixed with the undersize from the screen and sent to the grinding section. The whole operation is automatic, the

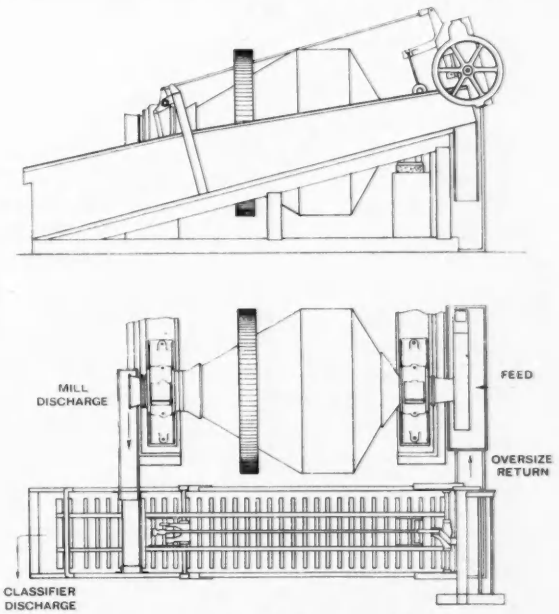


Fig. 3.—Ball mill and classifier unit.

products being transported from point to point on belt conveyors. Fig. 1 is a diagrammatic layout of the usual type of installation. The finished product, which collects in the fine ore bin, constitutes the feed to the grinding section.

Grinding.

The grinding unit employed is composed of a ball mill in *closed circuit* with a classifier. Its position in the plant can be seen from fig. 2. Fig. 3 shows such a unit with a conical ball mill and rake classifier. The ball mill consists essentially of a

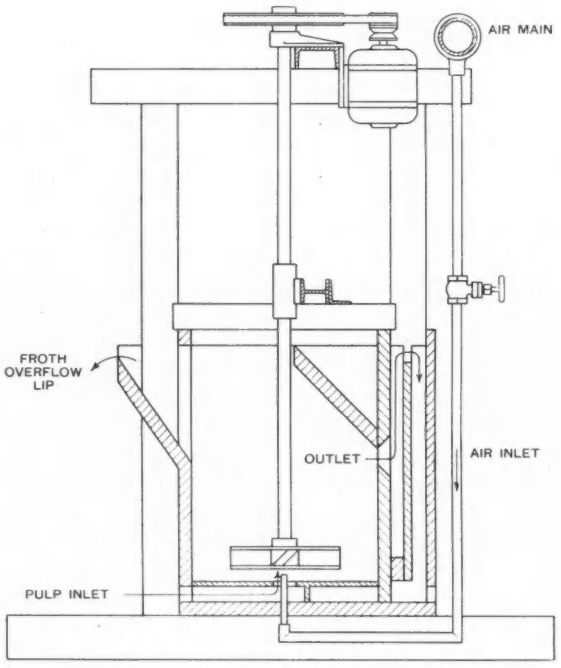


Fig. 4.—Sectional view of Minerals Separation flotation machine.

conical or cylindrical steel shell supported on hollow trunnions which run in bearings of large diameter (see figs. 8 and 9). The interior of the shell is lined with hard cast iron or steel plates to resist abrasion, and is filled nearly to the level of the centre line with steel balls. The mill is rotated at the speed at which the rolling and cascading action of the balls has the maximum grinding effect, usually between 20 and 30 r.p.m. depending on the diameter of the shell. The ore is fed automatically at a predetermined rate into the feed-end trunnion with about 30 per cent by weight of water. The ground ore passes continuously out of the discharge trunnion at the other end in the form of a thick *pulp*, and flows to the classifier, where extra water is added to form a more dilute *pulp* containing 25—35 per cent of solids. The classifier usually employed consists of a shallow sloping tank fitted with oscillating rakes. In the dilute pulp, particles that are larger than a certain critical size sink to the bottom, while the finer material or *undersize* continuously overflows the discharge lip at the end of the tank, the actual size at which the separation takes place depending on the density of the pulp in the classifier.

At each upward stroke of the rakes the layer of *oversize* that has collected on the bottom is moved a few inches up the tank, but the mechanism is so arranged that the bed is not disturbed during the descending stroke, which takes place five or six inches clear of the bottom. The oversize so raked up drops over the upper lip of the classifier-tank and is washed down a launder to the feed-end of the mill. There it mixes with the incoming dry feed and undergoes further reduction in size during its passage through the mill, circulating in the same way until it is fine enough to overflow the discharge lip of the classifier. Closed-circuit grinding with circulation of the oversize as described above is always used in modern practice as being the most efficient method yet devised.

It has been already explained that 50 mesh usually constitutes the upper limit of grinding, because in the case of most minerals particles larger than that cannot be made to float. Theoretically there is no lower limit, but in practice it is governed by considerations of cost and lies as a general rule at about 200 mesh; it is usually too expensive to grind an ore finer than this. Grinding to 250 or 300 mesh is not practised even in cases where to do so would enable a higher recovery of the valuable minerals to be made.

Flotation.

The flotation section follows the grinding section as shown in fig. 2. It contains a series of flotation cells, which are sometimes preceded by a conditioning tank. The latter consists essentially of a cylindrical tank with a cruciform impeller rotating in the bottom, the direction of rotation being such as to throw the pulp downwards and outwards. Its purpose is to *condition* the pulp; that is, to stir into it certain oils and chemicals, which are described later.

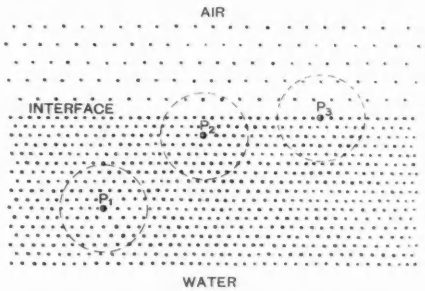


Fig. 5.—Diagram to illustrate surface tension of water.

The pulp from the grinding section is fed into the tank in which it is circulated for a predetermined length of time before entering the flotation cells. A conditioning tank is essential in the treatment of ores which require a definite period of contact with the reagents. But when the contact time is not critical, it is often possible to add the slow-acting reagents to the grinding circuit and the quick-acting ones to the flotation cells, in which case the pulp can be sent direct from the grinding section to the cells, the conditioning tank being omitted.

The flotation cells constitute the machine in which the actual concentrating operation takes place. A common type of machine is shown in section in fig. 4. It consists of a number of square cells with a four-bladed impeller rotating in the bottom of each over an air inlet-pipe. The conditioned pulp enters continuously at one end and passes from cell to cell in series. Low-pressure air is blown in under each impeller and is broken up into minute bubbles by the violence of the agitation in the bottom of the cell. The bubbles rise to the surface of the pulp, which is a few inches below the overflow lip of the machine, and would break there were it not for the presence in the pulp of a frothing reagent. This has the effect of stabilizing the bubbles to the extent of enabling them to collect on the surface as a more or less stable froth very similar to the lather produced when soap is beaten up in water. Another of the reagents used possesses the property of filming the surfaces of the minerals to be concentrated, making them what is in effect greasy, that is, water-repellent. In the lower zone of agitation of the cell these filmed particles are continually colliding with each other and with the air bubbles. The result is that each bubble rises to the surface coated with a layer of mineral particles, which tend to remain there by reason of the water-repellent nature of their surfaces, being held in place by an attractive force greater than gravity. Unlike the mineral, the particles of gangue are not affected by the reagent and have no tendency to collect at the surface of a bubble. They are in continual collision with other particles both of mineral and gangue and with the bubbles, but under the influence of gravity they drop out of any bubbles into which they may have been forced and so are not carried up in any quantity into the mineral froth that collects on the surface of the pulp. A rotating paddle scrapes the froth into a launder at the side of the cell as fast as it forms.

This action takes place in every cell as the pulp travels from the feed-end of the machine to the discharge-point in the last cell, but the froth carries less and less mineral in each succeeding cell, being almost barren in the last one. A launder along the side of the machine serves to collect the mineral-laden froth, or *concentrate*, while the barren residue, or *tailing*, flows to waste down a separate tailing launder.

Disposal of Concentrate and Tailing.

The concentrate as it comes off the cells may contain 70 per cent or more of water. The operation of dewatering it is performed in two stages. First, as much water as possible is removed in a thickener in a process of continuous settlement, in which a thick pulp containing 55 to 65 per cent of solids is drawn off at the bottom of a circular tank, while the bulk of the water is overflowed at the top as clear liquid. The thickened underflow then passes to a vacuum filter from which the concentrate is discharged as a cake containing about 10 per cent of water. This is dry enough to be stored in a bin or transported by a belt conveyor to the smelting or other process by which the crude metal is obtained from the mineral concentrate. The reason for the preliminary stage of thickening is that a decanting operation is much less expensive than vacuum filtration. Treatment costs are therefore lower when the maximum amount of water is decanted before filtration.

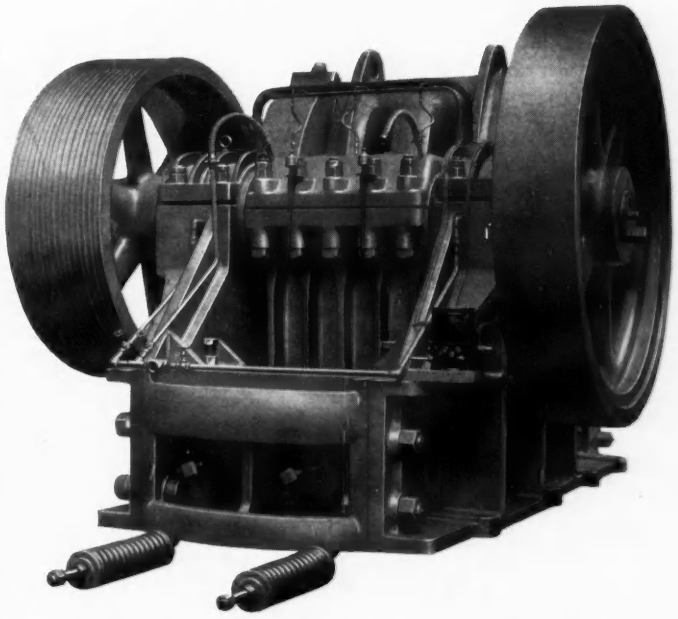


Fig. 6.—Fraser & Chalmers jaw breaker for primary crushing of ores.

The tailing is generally laundered to a pond or dam in which the solids are deposited and the water decanted off for return to the plant if desired. The walls of the dam are usually built up as required

with settled tailing dug or scraped from near the edge.

The above outline gives the main features of a complete flotation installation. Some of the machines and circuits employed in the flotation section will be described later, but detailed particulars of the accessory equipment in the other sections are outside the scope of this article.

FLOTATION REAGENTS.

In order to appreciate the manner in which the minerals are concentrated in a flotation machine, some understanding is necessary of the physics and chemistry of the action of the flotation reagents employed in the process. A detailed explanation would be too lengthy for the purposes of this article, but a description is given of the essential aspects of the subject with particular reference to the functions of the two most important reagents—frothers and promoters.

For further information the reader is referred to existing literature on the subject.[1]

Froth Production.

The production of a mineral-bearing froth depends for its effect on the surface-energy, or potential energy in the outermost layers of molecules,

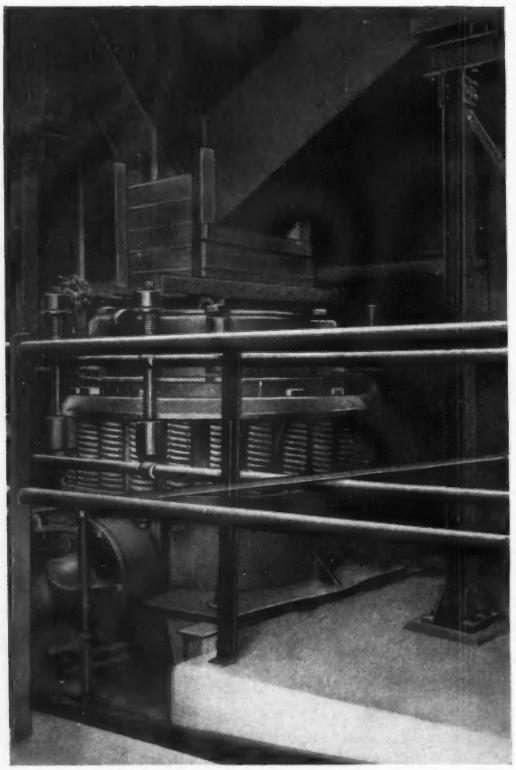


Fig. 7.—Symons cone crusher for secondary reduction of ores.

possessed in varying degree by all liquids and solids. This energy is the result of the attractions existing between the molecules composing the substance, the nature of which determines its physical properties of cohesion, hardness, viscosity, etc. In the case of a liquid the effect takes the form of a *surface-tension.*

As regards liquids, the only one that need be considered in connection with flotation is water. In a mass of water, or any other liquid, the molecules composing it exert a force of attraction upon one another which decreases very rapidly with decreasing distance; Edser[2] has calculated that it probably varies inversely as the 8th power of the distance separating one molecule from another.

Owing to the minute size of the molecules, the attraction becomes negligible at a spacing which is probably of the order of five millionths of a millimetre. The molecules themselves are in rapid and continuous movement, and in a process of continual ionization. In order to understand the conditions which give rise to surface-tension, it is necessary to consider what is happening at an instant of time so short that the molecules can be assumed to possess no motion. This is assumed to be the case in the mass of water illustrated in fig. 5.

The circles in fig. 5 represent the spheres of attraction of molecules P_1, P_2 and P_3. Molecule P_1, which is in the interior, is attracted equally in all directions by the molecules within its sphere of attraction. But the attraction of P_3 by the molecules in the lower half of the sphere is not counter-balanced by the upper half, which is above the surface of the water, or *air-water interface,* because the molecules of air and other gases there are very widely spaced compared with those in the lower half and exert a negligible attraction. P_3 is, therefore, subject to an attractional force tending to pull it into the interior. Similarly molecule P_2, situated just below the interface, is subject to a similar though weaker attractional force. A tensionary force, or surface-tension, thus exists in a layer of minute thickness on every liquid surface, and its value is measured by the work that must be done to move a

1. The following contain most of the literature on the theory of flotation :—

H. L. SULMAN. "A Contribution to the Study of Flotation." Transactions, Institution of Mining and Metallurgy, vol. 29 (1919-1920).

E. EDSER. "Molecular Attractions and the Physical Properties of Liquids" and "The Concentration of Ores by Flotation." Fourth Report on Colloid Chemistry and its General and Industrial Applications, Dept. of Scientific and Industrial Research (1922).

Transactions, American Institute of Mining and Metallurgical Engineers (1930): Volume on "Milling Methods," section on Flotation.

A. M. GAUDIN. "Flotation." McGraw-Hill Book Company, New York (1932).

Papers by I. W. WARK and A. B. COX, and by A. M. GAUDIN. Journal of Physical Chemistry, vols. 37, 39, 40 and 41.

Transactions, American Institute of Mining and Metallurgical Engineers (1934): Rocky Mountain Fund Volume on "Milling Methods," section on Flotation Theory and Practice.

G. R. M. DEL GIUDICE. "Fundamentals of Flotation." Engineering and Mining Journal, vol. 135 (1934), Nos. 4, 5, 6 and 8.

Transactions, American Institute of Mining and Metallurgical Engineers (1936): Technical Publications Nos. 659 and 732.

2. E. EDSER: "Molecular Attractions and the Physical Properties of Liquids." Report on Colloid Chemistry (1922).

molecule from the interior to the surface against the attractions of the other molecules. Water has a high surface-tension (72·8 dynes per centimetre at 20° C. at an air-water interface) as compared with other liquids whose specific gravity is near that of water, such as ethyl alcohol, benzene, petroleum, turpentine, etc.; the surface tension of these other liquids is between 20 and 30 dynes per centimetre.

The effect of surface-tension is to contract the surface of the liquid to a minimum area. This accounts for the spherical shape of bubbles in water, since a sphere presents the minimum area for a given volume, and for the fact that, if two bubbles collide, they will coalesce to form one larger one. It also accounts for the bursting of the bubble when it reaches the surface. In order to prevent the coalescence of air-bubbles in water and to enable them to persist as a froth when they reach the surface, both of which conditions are necessary for flotation, some elasticity must be imparted to the surface of the water. This is done by means of a *frothing reagent*.

One requirement of a frothing reagent is that its molecules shall possess a lower attraction for water than the molecules of water have for one another. It must also be soluble in water (actually sparingly soluble, for reasons explained later), without appreciable ionization. When a small quantity of such a compound is dissolved in water, its molecules are virtually pushed out of the interior of the liquid mass into the surface-layers by the superior attraction of the molecules of water for each other. The result is that the molecules of the reagent are concentrated, or *adsorbed*, at the liquid surface. Complete adsorption is prevented by molecular movement, but the degree of concentration of the reagent in the surface layers is high.

Contamination of the surface-layers of water in this way by foreign molecules reduces the surface-tension, since the molecules of reagent are not pulled towards the interior with such force as the molecules of water which they have displaced. For flotation purposes the least possible reduction in surface-tension is desired, as will be explained later. The presence of the foreign molecules also imparts elasticity to the surface-layers in much the same way as if they were covered with a rubber membrane. Stretching the surface of a membrane increases its tension. Thus, if two air-filled rubber balloons rising in water collide, their surfaces are temporarily deformed and stretched. but the increased tension of the rubber skin pulls them into shape again and they bounce away from each other. Stretching the surface of pure water, however, results in no increase in tension; its surface-tension is invariably constant. If two air-bubbles rising in pure water collide, their surfaces break at the point of contact and the bubbles coalesce. But in the case of water to which the correct amount of reagent has been added for frothing purposes, stretching the surface will bring more molecules of water into the stretched layer, momentarily increasing the tension; the increased tension will then pull the surface back into shape again. Thus the foreign molecules impart elasticity to the surface of the water. They will be concentrated in the same way at the air-water boundary of all bubbles blown into the water. Two bubbles rising under these conditions will bounce away from each other after a collision as though they were surrounded by rubber membranes. If some circumstance prevents the surface from being pulled into shape after deformation, extra molecules of the reagent will be forced from the interior of the water to the surface after a short time-lag, so re-establishing the tension at substantially the same value as before over the enlarged area. Thus, when an air-bubble rising in water reaches the surface, a skin of water is pulled up over the projecting portion as it emerges, and the momentary increase of tension due to this enlargement of the surface of the water prevents the skin from rupturing, though it is not great enough to keep the bubble down. Its upward movement is checked, however, for sufficient time to allow extra

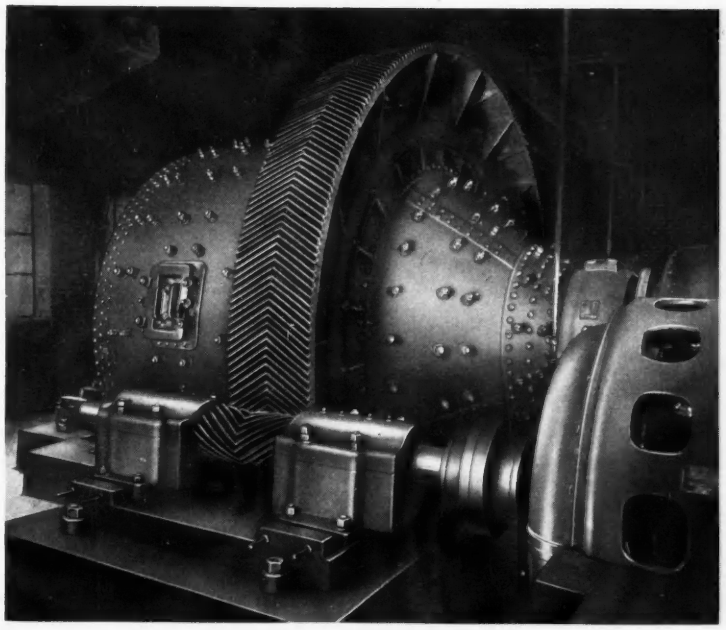


Fig. 8.—Hardinge conical ball mill.

molecules of the reagent to enter the projecting surface and re-establish the original tension. This happens all the time that the bubble is rising above the normal water-level, enabling it to emerge completely covered with a film of water, which is elastic by virtue of the foreign molecules of the frothing reagent adsorbed at its boundaries, both inside and out.

Frothing Reagents.

The preceding explanation of the mechanism of frothing enables the properties of a frothing reagent to be specified. It must be soluble in, or at any rate miscible with, water in order that it may become part of the liquid system, or *liquid phase*, but its molecules must also possess a strong tendency to concentrate at the air-water boundaries. These requirements rule out *nonpolar* compounds such as kerosene and similar hydrocarbons, which, as a class, do not dissolve in or mix with water. They can be described as organic compounds which show no polarity in their atomic structures; it should be noted that this is not a full definition. *Polar* compounds, such as inorganic salts, which show definite polarity in their structures, are also useless as frothing reagents because they are strongly attracted by water and ionize in it. They therefore tend to become drawn into the interior of the liquid and not to concentrate in the surface layers. A frothing reagent must evidently possess properties intermediate between those of the above two classes. It must be slightly soluble in water and at the same time possess a strong tendency to concentrate at the air-water boundaries. These characteristics are found in certain members of a class of organic substances termed *polar-nonpolar*, or *heteropolar*, compounds, which contain both polar and non-polar groups in their molecules. The polar part, containing a group such as *OH*, *COOH*, etc., is attracted by water. The nonpolar part, which consists of a hydrocarbon chain, is repelled by water and tends to concentrate in the surface layers. A polar-nonpolar compound. therefore, having a water-repellent hydrocarbon chain and a polar tail that is just strong enough to anchor it in the water without drawing it into the body of the liquid, furnishes the requirements necessary for good frothing reagent.

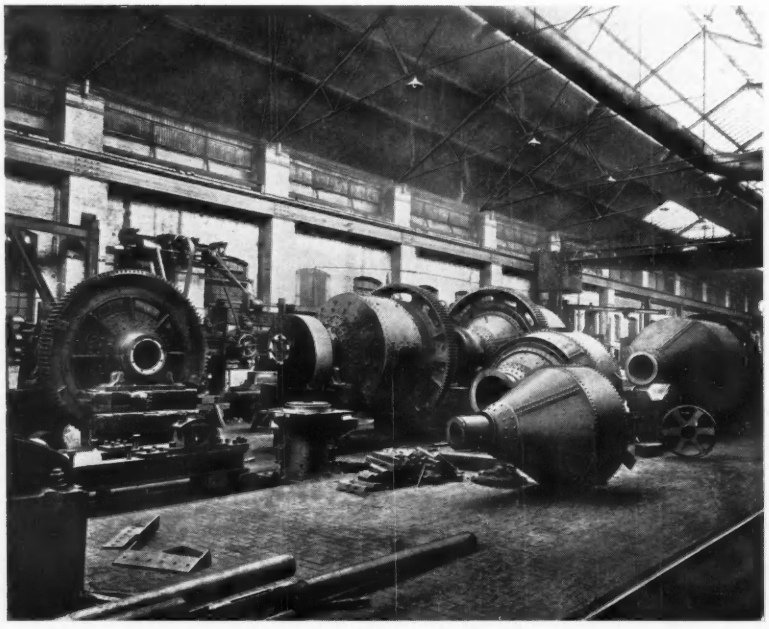


Fig. 9.—Hardinge conical ball mills under construction at Fraser & Chalmers Engineering Works.

In a homologous series of compounds of this class it is the length of the hydrocarbon chain which determines the solubility of any member of the group. This is to be expected, as the polar group is the same throughout the series and its degree of attraction to the water is therefore constant, but the nonpolar group increases in length with every ascending member of the series, and thus pulls the polar tail out of the water with increased strength until the outward pull is too strong to enable the compound to mix with the water at all, when it becomes insoluble. The aliphatic alcohols illustrate this effect. The lowest member of the series,

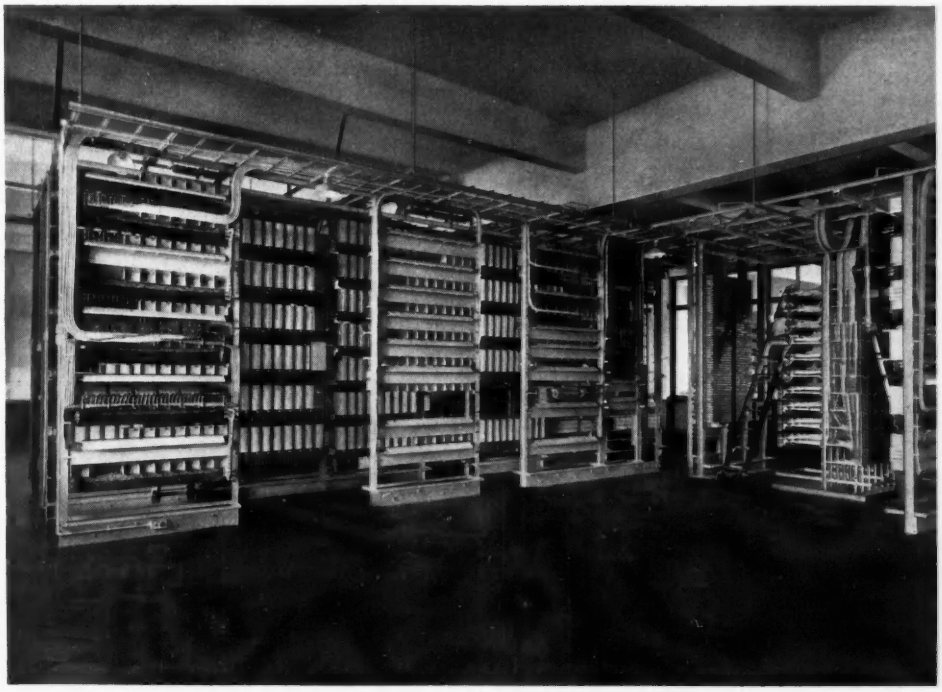
methyl alcohol, $CH_3.OH$, is very soluble in water and exhibits no frothing properties. The same is true of the next two members, ethyl alcohol, $CH_3.CH_2.OH$, and propyl alcohol, $CH_3(CH_2)_2.OH$. Note how the addition of the CH_2 group is increasing the length of the hydrocarbon chain. Frothing properties begin to appear with the next member, $CH_3(CH_2)_3.OH$, and the addition of one more CH_2 group makes amyl alcohol, $CH_3(CH_2)_4.OH$, a good frother. The next higher members of the series, $CH_3(CH_2)_5.OH$, $CH_3(CH_2)_6.OH$, etc., are still better frothers, but the pull of the hydroxyl (OH) tail is becoming barely sufficient to keep the hydrocarbon group in the water, and the loading becomes too great at about $CH_3(CH_2)_8.OH$, at which point and above the compounds are so insoluble that they cease to possess frothing properties. It should be noted that the very slight solubility of $CH_3(CH_2)_6.OH$ and $CH_3(CH_2)_7.OH$, which would be regarded as insoluble in water for most purposes, is sufficient for frothing, because the film of reagent concentrated at the air-water bubble-surfaces need be no more than one molecule in thickness; it is, in fact, quite possible that the film is not even monomolecular, but that the molecules are interspaced with those of water. This would explain the very small amount of reagent required to produce a froth, which is of the order of 0·005 per cent by weight.

Although the alcohol frothers mentioned above are employed in the flotation of certain ores, they are too expensive for general purposes, and a cheaper type is more commonly used. The most popular is a *pine oil* obtained by the steam-distillation of certain species of American pines. It consists of terpene alcohols ranging from about $C_{10}H_{15}.OH$ to $C_{10}H_{19}.OH$, which are the main frothing constituents, mixed with some more or less inert terpene hydrocarbons. The only other frother in common use is *cresylic acid*, which is rather less powerful in its action than pine oil. Its frothing constituents are cresol, $CH_3.C_6H_4.OH$, and xylenol, $(CH_3)_2C_6H_3.OH$, but it also contains a small proportion of inert hydrocarbons.

The amount of these reagents needed to produce a froth is very small. In normal operation the consumption of pine oil is from 0·05 to 0·15 lb. per ton of ore, while that of cresol is slightly more, ranging from 0·1 to 0·4 lb. per ton.

(*To be continued*).

Automatic Telephone Equipment at Bangkok.



Automatic telephone equipment at Bangrak Enchange, Bangkok. One of the two automatic exchanges—the first in the City—installed by the G.E.C. for the Royal Siamese Posts and Telegraphs Department.

Lighting in Shops and Stores.

By R. O. ACKERLEY
G.E.C. Illuminating Engineering Department, London.

THE field covered by this title is so wide that it is desirable to limit the subject as much as possible, bearing in mind that the essential respect in which shop lighting differs from other forms of lighting must be that directly, or indirectly, it should contribute to the art of selling.

The term shop premises includes restaurants, offices, waiting rooms, and so forth, and there is no reason for treating the illumination of such portions of the shop in any different way from that in which similar rooms in any other building would be treated. It is therefore proposed to consider the subject purely from the point of view of those forms of lighting which may help the primary object of the establishment of any shop, namely, the selling of goods.

Fig. 1.—Floodlighting provides one of the simplest and most dignified means of attracting attention from a distance.

Lighting may contribute to this end in various ways of which the following are probably the most important :—

(*a*) By attracting from greater or less distances the attention of passers-by.
(*b*) By drawing attention to bargains and special lines.
(*c*) By showing off goods to the best possible advantage, in such a way as to bring out their quality.
(*d*) By creating a pleasant atmosphere for customers.
(*e*) By combining with the last quality features of decoration and novelty that in themselves attract customers to the building.

LIGHT SOURCES.

It is proposed to deal with the different classes of lighting in the above order, but, first, consideration will be given to the various electric light sources which are available. Up to a very short time ago, the tungsten filament lamp in some form was practically the only electric light source which could be employed for the interior lighting of shops. Cold cathode neon tubes and hot cathode electric discharge lamps have for some years been used for exterior lighting effects, but up to 1936 tungsten lighting had been used practically without exception in shop interiors.

Since that date two forms of light source have been introduced which may play a revolutionary part in the shop lighting field. The first of these is the Osira fluorescent tube. The development of these tubes will be dealt with fully in a future article, so that for the present only their salient features, in so far as they may affect shop lighting, will be described. These features are their high efficiency, which for the first time enables cold cathode electric discharge tubes to compete economically with tungsten lighting; their low surface brightness which allows them to be used, if desired, as visible light sources ; and the fact that by blending suitable colours a resulting colour of light of almost any degree of warmth can be obtained, including an approximation to natural daylight far closer than that obtained from tungsten filament lamps.

The other light source which bids fair to revolutionise shop lighting is the Osira high pressure mercury lamp. By itself this light source is deficient in red light, but the introduction of 80 and 125 watt Osira lamps gives us a source which is ideal for blending with tungsten filament lamps. The excess of red light in the tungsten lamp fills the deficiency of red light in the Osira lamp, the resultant light when mixed in suitable proportions being again very close to that of natural daylight, while an additional vitality is imparted to the goods on which such light falls.

EXTERIOR FLOODLIGHTING.

The importance of attracting a customer from a distance needs very little stressing. The provision of lighting for this purpose is a form of trade name advertising and a constant reminder to the public that a shop selling a certain class of goods exists at a certain place.

The two principal methods for attracting attention from a distance by light are floodlighting and electric signs. Wherever a building has any claim to architectural distinction, and where any reasonable portion of the facade can be seen from a distance, floodlighting offers the most dignified and effective solution (see fig. 1).

To attract attention from a great distance there should usually be some floodlighting high up on the building; towers, cornices, etc., lend themselves well to this purpose, but it is essential, if much of their utility is not to be lost, that there should be some form of connecting link between the floodlighted upper portion of the building and the lower portion. Unless this is provided, there is danger that by the time the prospective customer gets near the building, the floodlighting will be above his line of vision and will have no connection in his mind with the shop it is intended to advertise.

From the point of view of building design, it is of the greatest importance that the possibilities of floodlighting should be envisaged in the early stages. There are buildings already in existence where the architect has appreciated the importance of floodlighting to such an extent that the facade has been definitely designed with a view to its floodlighted appearance.

If it is too much to suggest that in commercial buildings facades should be designed more from the point of view of their night appearance than their day appearance, it is at least sound to suggest that facilities should be provided so that if the building is to be floodlighted, the floodlights can be mounted to give the best possible effect. The provision of suitable projecting balconies, parapets, etc., behind which floodlights can be concealed sufficiently offset from the building to make good light distribution practicable, make all the difference between good and bad results. Where no facilities exist for screening floodlights on the building it is possible to mount the floodlights on projecting brackets, screening them with some sort of decorative leafwork or similar design, but a building so treated will never look so effective as one in which the floodlights are concealed in the building structure itself.

The choice of correctly designed floodlighting equipment and its correct placing is essential if satisfactory results are to be obtained. The requirements as regards light distribution are directly dependent on the shape and architectural design of the building and the facilities available for placing floods; floodlights which would give excellent results in one position may be entirely unsuitable in another. In many cases a very limited offset is available and equipment specially designed for such conditions must be employed. Correct focussing and training are also of supreme importance and special care in this respect will amply repay the time spent on it.

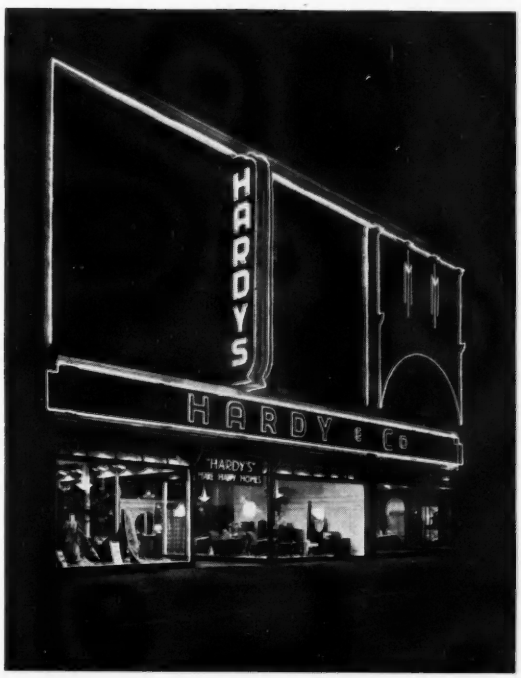


Fig. 2.—An effective electric sign and neon display linking the top of the building with the shop windows.

SIGNS.

The other method by which attention can be attracted from a distance is by the use of illuminated signs. There are many types of signs on the market and one consideration in selecting a sign for this purpose would seem to be that its day appearance must not be unattractive. Here again the appearance of the whole building will be much improved if the sign can be embodied as part of the main structure and, as in the case of floodlighting, it is important that there should be some visual connection between any sign at the top of the building and the lower portion of the building (fig. 2). From this point of view vertical signs are particularly effective, and a good example of how such signs can be made an integral part of the building—looking equally effective by day and night—is found in the type of sign where metal letters are shown up in silhouette against an illuminated cove built into the corner of the building. Many other types of sign with attractive day and effective night appearance are available, of which space does not permit description, but some reference must be made to neon signs. The effectiveness of neon tubes, whether in the form of letters or

purely for providing a spectacular display, has been recognised for many years, but until recently the range of colours available was limited and shopkeepers were justifiably demanding something new. To-day, neon tubes are available in twenty-five colours spread over the complete spectrum and

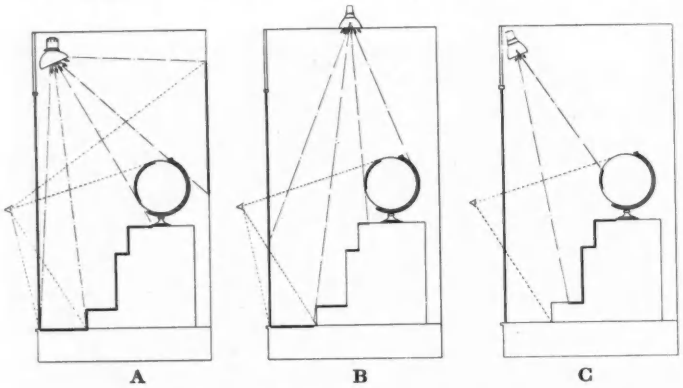


Fig. 3.—Illustrating the amount of display space in a window effectively illuminated under various systems when viewed by an observer outside the window. Figure A shows the light being directed evenly all over the window and from the front in such a way that it strikes the side of the goods towards the observer. Figure B indicates how with overhead mounting the side of the goods towards the observer receives relatively little light. Figure C shows a system where the light is concentrated mainly into the centre of the window and much of the display space at the front and back is relatively unilluminated.

including some extremely attractive pastel shades. These tubes, many of which are manufactured under Cleora patents, are also notable for their high efficiency and brilliancy.

Apart from permanent signs, for which some sort of provision will usually have to be made on the original building structure, it is often desirable to erect temporary signs to draw attention to sales, or other special occasions, and it is suggested that some sort of provision in the stonework, to which metal frames for the mounting of temporary signs can conveniently be fixed, should be an essential feature of any large store. The importance of adequate provision of electric mains, preferably in the form of watertight plug connections, should not be overlooked.

A recent development in outside lighting, which does not appear under the heading of signs or floodlighting, is the use on the outside of the building of built-in lighting features as part of the building structure. While in the majority of examples available in this country, such built-in features have been confined to the window and door surrounds and the fascia, there is no reason to limit them in this respect, and they may still become one of the recognised forms of luminous advertising in commercial architecture.

In this connection, recent developments in the technique of glass manufacture provide new possibilities for the architect wishing to obtain spectacular lighting effects. Glass bricks call for a very specialised lighting technique while coloured glass rods and the varieties of fluted glasses now available lend themselves to such external effects.

There is one other method of attracting the attention of people close to a building which should not be overlooked, and that is by the use of "stunt" window lighting, involving moving or flashing devices in conjunction with spectacular colour effects. The use of such window lighting can only be regarded as in the same class of sales aid as floodlighting and signs, in that it is designed to attract attention rather than to show off the goods in the window to the best advantage. For this reason, in view of the importance of show windows as a straightforward sales aid, the employment of "stunt" lighting, except perhaps in one window out of a number or as an occasional short period change in smaller premises, should not be encouraged.

THE VALUE OF SHOW WINDOW LIGHTING.

Under the second heading given at the beginning of this article, namely, attracting attention to bargains available, and emphasising the quality of goods, the most potent aid is good window lighting. As a preliminary to considering this subject it may be interesting to examine to what extent good lighting increases the value of show windows. A survey recently carried out in both central and suburban areas shows that, calculating capital charges on a 10 year basis, the cost of a first class lighting system is only 7 per cent to 10 per cent of the cost of the windows. As, however, the windows are useless after dark unless illuminated, this small percentage extra cost adds approximately $33\frac{1}{3}$ per cent to the working hours of the displays. These remarks might, of course, be said to apply to any system of lighting which made the goods visible, but other tests indicate that the stopping power of an illuminated window display is directly affected by the intensity of the illumination as the following table shows:

Tests Taken in a Main Shopping Thoroughfare.

Illumination— Foot-candles.	*No. of people stopping per hour.*
15	200
40	244
100	284

MIRROR GLASS REFLECTORS.

For many years the most popular and generally recommended type of window lighting has been by means of mirror glass reflectors placed immediately at the back of the window pelmet and directing the light more or less evenly over the whole of the window from front to back and from top to bottom.

There is a natural tendency for enterprising shopkeepers to ask for something new, but while modern and original ideas undoubtedly can be introduced as methods of employing such reflectors, the fundamental lighting principles on which this system was designed are as sound to-day, in relation to tungsten lamps and light sources of similar general shape, as they were when they were introduced and, subject to the possibilities presented by the employment of new forms of light source, any modification in window lighting should be based on the use of such directional lighting reflectors.

The reason for the superiority of this system for general lighting of shop windows may be simply explained. The customer looking into the display window can only see those sides of the goods which are facing towards the glass, and therefore to be useful light must strike the goods from that direction. To achieve this in the best way, the lighting equipment must be placed as close as possible to the glass and can only be installed at the top or bottom or

Fig. 4.—Indirect lighting in a motor car showroom shows off the highly polished body work.

somewhere intermediate between these two positions. In the intermediate position, the lighting equipment would interfere with the clear view of the goods displayed, while if the lighting equipment is placed at the bottom, it tends to occupy useful window space and is at the same time almost inevitably visible to the customer in the street. At the top of the window, however, it can be placed right outside the line of vision and concealed from view behind the pelmet. The use of individual reflectors

Fig. 5.—An original method of using architectural lamps for counter illumination.

for each lamp allows maximum flexibility in spacing and switching and lends itself to the use of colour screening when desired. Furthermore, the reflectors, when properly designed, can be extremely efficient in the sense that a very high percentage of the light output of the lamp can be directed where it is most useful, that is to say, on to the goods (fig. 3).

Certain types of window lighting reflector tend to concentrate a very high intensity of light on to a comparatively narrow area in the centre of the window. While this treatment may be suitable in a limited number of cases where the goods are of such a nature that they lend themselves to display in the centre of the window, and the centre only, as a general rule the window-dresser likes to have latitude to adjust his display without limitation as to the position in the window where his goods will show to advantage, and for this reason a type of reflector which distributes light evenly over the whole area is far more flexible than one of the more concentrating type. With this system, goods right against the front glass of the window and those high up at the back are as well illuminated as those in the centre, and, if it is desired to increase the light in any particular part of the display, auxiliary spot and floodlights can be employed.

WINDOW LIGHTING AUXILIARIES.

While spot and floodlights should be considered primarily as auxiliaries to the general system of lighting, there is an increasing tendency in the

better class shops to employ such units for short periods without the general lighting so as to give special dramatic effects. In this way one article or even a small part of an article may be made to stand out in brilliant relief against a dark or coloured background. This is a typical instance of the

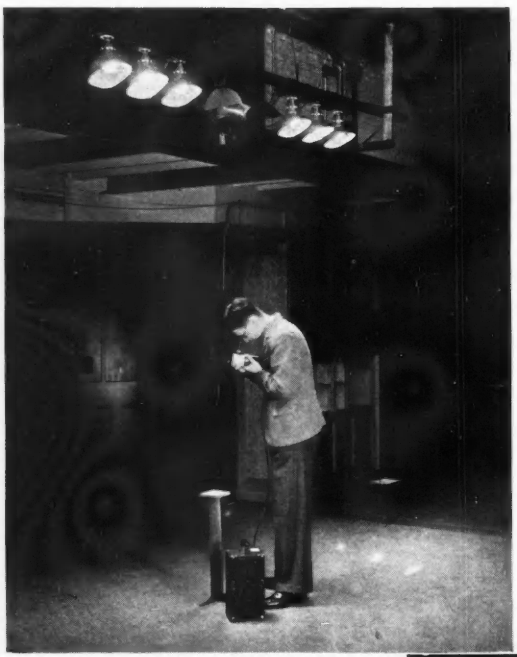


Fig. 6.—Studying light distribution and intensities from a mixture of tungsten and Osira mercury lamps arranged as shown in fig. 12.

manner in which the flexibility of an individual reflector system can be used to provide "something different."

Various other forms of auxiliary lighting can be introduced which, in one way or another, add life or variety to the resultant display. Such systems include the installing of special architectural features, such as laylights, box recesses and other architectural motifs, to conceal the reflectors, auxiliary side and bottom lighting, and luminous units in the window.

With regard to the latter, however, great care must be exercised, as if such luminous features have too great a surface brightness they will make it difficult to distinguish detail in surrounding objects, and thus detract from the window display instead of enhancing it. A good way, therefore, of obtaining such luminous effects is by means of indirectly lighted insets.

The very latest type of luminous effects is obtained with the aid of fluorescent dyes and pigments illuminated by Osira black glass lamps. With such a display the articles treated stand out in brilliant colours against an unlighted background. The method is therefore more applicable to advertising material and symbolic displays than to actual goods.

Arcades and island windows are always a problem to the illuminating engineer as there is difficulty in lighting a window in such a way that the illumination is effective and at the same time concealed when viewed from all sides. The author's own opinion is that an island window should be lit from the street frontage as, first, this is the direction towards which the main scheme of dressing is normally directed and, secondly, by the time the prospective customer has walked round to the other side of it, one of the main purposes of the lighting, namely attracting the customers to look at the windows, has been achieved. An attempt to light an island window from all sides usually results in spoiling the effect from all sides.

The general lighting of arcades, as distinct from the lighting of the windows themselves, should be confined to the use of units of low surface brightness so that the eye is not drawn away from the window

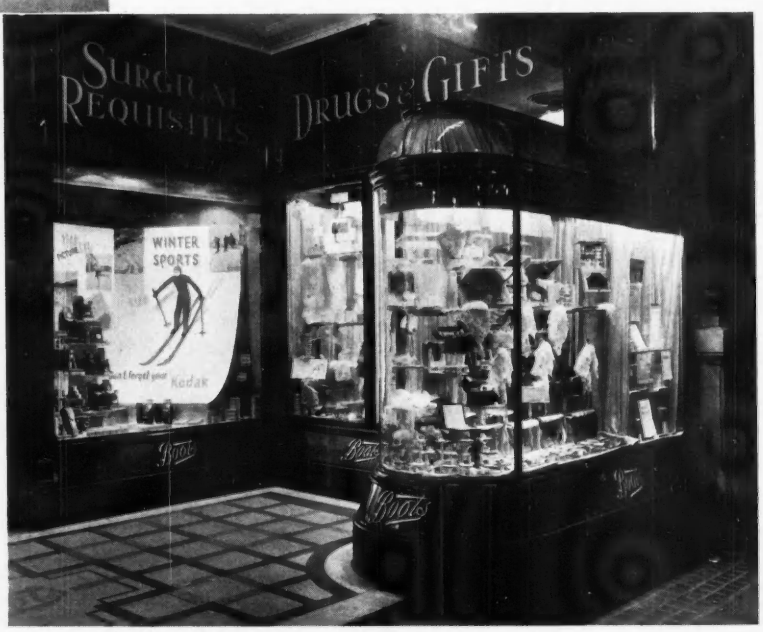


Fig. 7.—"T.O.T." shop window lighting (from a mixture of tungsten and Osira mercury lamps) adds life and sparkle to the goods displayed.

displays. Many arcades rely on the light spilt from the windows for their sole lighting, but, as an

alternative to this, indirect lighting from the top of the showcase may be employed to advantage, while architectural lighting, provided surface brightness of individual units is kept sufficiently low, will often add a touch of life to the arcade as viewed from across the street. Fluorescent tubes and architectural lamps are particularly suited for providing illumination in such positions (see fig. 8).

COLOUR IN SHOW WINDOWS.

As regards the use of colour in window lighting, the question of "stunt" lighting to arouse the curiosity of passers-by has already been mentioned, but for straightforward window lighting, designed to show off the goods to the best possible effect, colour should only be used subserviently to the main lighting, otherwise the goods themselves will suffer from colour distortion. Striking effects can be made however by concentrating the colour, either in one fixed batten, or changing by means of flashers or dimmers, on the background, while the goods in the foreground remain illuminated with white light.

Certain classes of goods benefit by a slight touch of colour in the light. Furs, for example, show up best under a slightly bluish light while certain foodstuffs are enhanced by a tint of amber or pink. Such tinting needs to be very slight and is best obtained by means of special reflectors in which the glass is tinted. By this method the reflected light takes on the colour of the glass through which it passes and blends with the direct light from the lamp which remains unaltered.

THE T.O.T. SYSTEM.

The possibilities of combining the light from high pressure mercury and tungsten lamps have been referred to at the beginning of this article. Experiments have shown that this can be done to great advantage in shop window lighting. The 80 watt Osira high pressure mercury vapour lamp, being of the same size and having the same light centre length as the 150 watt Osram tungsten lamp, lends itself to employment in existing shop window reflectors, and tests have indicated that to obtain the best mixing of the two colours of light, one Osira lamp should be placed between two tungsten lamps. This has led to the introduction of the "T.O.T." (Tungsten-Osira-Tungsten) system of shop window lighting developed by the G.E.C. (see figs. 6 and 7). The proportions of tungsten to Osira can be varied to requirements, two 150 watt tungsten lamps to each 80 watt Osira mercury lamp giving a very fair approximation to daylight colour ; it is therefore far more suitable than plain tungsten for the illumination of windows containing fabrics and dress materials. Where colour value is of less importance, two 100 watt tungsten lamps to each 80 watt Osira lamp give an added vitality and sparkle to the windows, while at the rates normally paid for current for window lighting, the high efficiency of the lamps results in a definite saving in running cost on each point equipped with an Osira lamp. Under the T.O.T.

Fig. 6.—Specially designed architectural lighting units in the corset department of Harrods, Ltd., London.

Fig. 8.—Sunlight tubing in the arcade provides soft lighting to contrast with the brilliance of the mirror glass reflector lighting in the windows.

Fig. 10.—A combination of louvred overhead lighting and spotlights imparts a dramatic quality to this display of models.

system the lighting layout must essentially be considered in groups of three lamps, and where individual reflectors are employed the three reflectors constituting a T.O.T. unit should be as close together as possible. Where it is not desired to have reflectors close together right across the window, any necessary gaps must be obtained between one group and the next, fig. 12.

As an alternative to using separate reflectors for each lamp, specially designed reflectors each housing three lamps—one Osira and two tungsten—can be used and are recommended in new buildings where it is not desired to take advantage of existing reflectors.

Osira fluorescent tubes in specially designed troughs have also been used successfully for shop window lighting either as the sole source of light or as an auxiliary to tungsten lighting.

INTERIOR LIGHTING, THE RELATION BETWEEN LIGHT AND SALES.

Turning now to the interior of the shop, where the showing off of the goods to the best advantage and the creation of a pleasant atmosphere are the chief requirements, combined with features of decorativeness and novelty that in themselves attract attention, it is proposed to deal mainly with the question of straightforward interior lighting designed to help to sell merchandise. It is well known that certain classes of goods tend to show up to particular advantage under certain systems of lighting. For instance, glassware can be made to sparkle under a direct system where it would appear comparatively dead under an indirect system.

Fig. 12.—Arrangement of "T.O.T." lighting system in which one Osira mercury lamp is placed between two tungsten lamps forming a series of groups of three lamps.

Fig. 11.—Special decorative diffusing glass pendant fittings are used to light the new Oxford St. premises of D. H. Evans & Co., Ltd., London.

The difficulty is to obtain any really reliable data to indicate what effect a change in lighting system has on the sales of any particular class of goods. So many causes affect sales that unless experiments can be carried out on a comparatively large scale it is impossible to say that a temporary improvement or drop in sales of goods of a particular class was influenced by the lighting and not by any extraneous conditions. Experiments, however, were carried out recently by the engineer of a number of large stores in this country with the object of testing the effect of interior lighting on sales, and some convincing results were obtained. The system on which he worked was along the following lines. Assuming at the beginning of the tests that the lighting in the corresponding department of several

different stores was of similar character, he would alter the lighting in one store leaving the others unaltered. If, following on this change in lighting, there was an increase of sales in the one store without any corresponding increase in the others, he would then introduce the new form of lighting into a second store. Up to this point he would still be up against the difficulty that he could not say how far the original increase in sales was due to the lighting, or how far it might be due to some entirely extraneous circumstance. If, however, he found, as was sometimes the case in the experiments made, that at the second store a similar increase in sales took place as soon as the lighting was changed, he had at least a *prima facie* case for thinking that the system of lighting had had a direct bearing on the sales.

If the result of such experiments were to show that a certain type of lighting, as, for instance, general diffused lighting, was the best for all classes of goods it would make the lighting problem very simple but, in practice, this is not the case, and it is found that some classes of goods respond best to lighting with a strong directional element, others to totally indirect lighting, and yet others to general diffused lighting, or a combination of any two of the above systems.

In the case of a general store dealing with all classes of goods, such results may lead to complications as, in the first place, in many cases the class of goods varies on one floor without any dividing line between the departments, and a different type of fitting in various sections of the same floor might look curious; and, secondly, in a store of this nature the management often like to feel that, at any rate as regards certain areas, they can change the nature of the goods displayed at short notice so that goods of seasonal, or other special interest, may have the most prominent positions at the proper times. It would lead to some complication if, every time the goods were so changed, the lighting fittings also had to be changed. There is, however, a method by which this difficulty can be overcome, at least to some extent, by having a dual purpose fitting wired on separate circuits, which can give two or more systems of lighting, either separately or in combination. Such a fitting might consist, for instance, of an upward portion concealing an indirect reflector throwing the whole of its light on to the ceiling, and a lower portion having lighting characteristics similar either to a diffusing glass fitting, or a directional lighting fitting. With such a fitting it is possible at a moment's notice, to change the lighting from general diffused effect to a totally indirect effect, or *vice versa*.

Fig. 13.—Dual purpose fittings of the type shown are used to provide either indirect or semi-direct diffused light to suit the goods displayed in many of Lewis's stores throughout Great Britain.

Such a fitting, fig. 13, has been used in some of the experiments referred to above, and it may be interesting to examine some of the results obtained and the probable reasons.

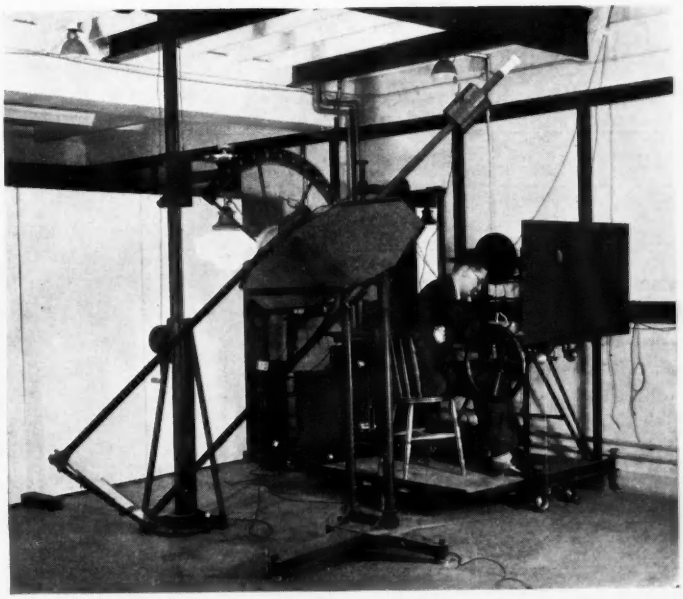


Fig. 14.—Examining the light distribution of a diffusing glass fitting with the aid of a polar curve machine at the G.E.C. Research Laboratories, Wembley.

GENERAL DIFFUSE LIGHTING.

The table on this page records a few typical results from which hard and fast rules cannot be made, but the results are interesting as an indication of what may be expected with other classes of goods. Where a shop is being built to sell goods of one nature only, then obviously the best form of lighting can be chosen for those goods. Where the shop is being built as a general store, dual purpose fittings may be installed as described above, but fittings of this nature are necessarily more expensive than straightforward equipment and where expense is a primary consideration, general diffusing fittings which combine to some extent the qualities of both

A B

Fig. 15.—A comparison of the illustrations above shows how the addition of high intensity louvred lighting over the display (illustration B) adds vitality and increases contrast without altering the general appearance of the sales floor.

Type of Goods	Type of Lighting Giving Best Results	Suggested Reason
Carpets	Direct Lighting	Shows up contrast between colours. As low reflection factor colours are usually involved there is no danger of over-brightness, nor are there possibilities of harsh shadows.
White Goods, Linens etc.	Indirect Lighting	The reflection factor of the goods is so high that direct lighting tends to create dazzle.
Glassware	Direct Light (preferably embodied in the display shelves)	Creates sparkle and gives life to the display.
Dress Materials	Directional Lighting	To give just that amount of shadow and gloss which shows material to good advantage.
Evening Dresses	Indirect Lighting (High Intensity)	Such goods are normally made for use under highly diffused lighting.
Furniture, Ironmongery	General diffuse lighting	Directional lighting would give too great high lights while totally indirect would not give sufficient.

direct and indirect lighting will probably prove the most satisfactory form of standard equipment (see fig. 16). Fittings of this class have been generally recommended for shop lighting for some time past and are found satisfactory in the majority of cases. It is, however, frequently desirable to augment this general lighting with directional lighting units on special areas both to provide high spots and to bring out special features of the goods, fig. 17.

HIGH INTENSITY COUNTER LIGHTING.

There is a tendency in all modern lighting schemes for illumination intensities to increase and in no field of lighting do high intensities give a better return than in shop windows and interiors. For some years illumination values of 100 foot-candles and upwards have been common practice in well lit shop windows, while in interiors, whereas a shop was considered well lit at 5 to 10 foot-

candles a few years ago, to-day 15 to 25 foot-candles are found in many English stores, and appreciably higher intensities are in vogue in America. The provision of high intensity lighting in windows is a simple matter as the lighting equipment can be hidden and the customer is outside the brightly lit area. In interior lighting, on the other hand, the problem of providing high intensity artificial lighting so that there is no sensation of oppression or glare to a customer looking in any direction is far more difficult. The problem is one of directing the requisite amount of light on to the goods without having visible light sources of excessive brightness. The most successful and simple way is by means of fittings embodying a mirror glass or other form of concentrating reflector mounted flush with the ceiling and directing its light downwards on to the displayed goods, suitable louvres being provided to cut off the light at an angle of about 45° so that no bright light is directed into the eye of the customer at any normal angle of vision (see fig. 15). This system, however, leaves the ceiling relatively dark and may give a tunnel effect. The overhead lighting should therefore be combined with indirect lighting on to the ceiling of just sufficient intensity to light the ceiling. By this method intensities of 50 to 100 foot-candles can be obtained on the display counters without any sensation of glare and with relatively small consumption of current. Show cases and fixtures will often be found to provide suitable mounting and concealment for reflectors to give the small amount of indirect lighting required. Alternatively, decorative floor or counter pylons will serve the purpose. As another alternative where plenty of height is available, the louvre units may be suspended below the ceiling and mounted in a composite fitting designed to give the necessary upward illumination.

Fig. 17.—Concealed floodlights directed on to the flowers in the London showrooms of Moyses Stevens, Ltd., effectively augment the general lighting.

Fig. 16.—General lighting by means of high efficiency diffusing glass fittings is simple and effective when adequate lighting is more important than decorative appearance.

OSIRA FLUORESCENT TUBES.

The possibilities of decorative treatment of fittings in any of these forms of lighting are unlimited and a matter for collaboration between the architect and fittings designer (see figs. 5, 9, 11). This subject is so vast that it must necessarily be left out of the present article. Some reference must, however, be made to the possible uses of Osira fluorescent tubes for interior store lighting. While these tubes can be used as light sources in cornices or behind laylights, in glazed troughs and similar ways, probably the

greatest possibilities lie in their use as visible light sources, in conditions which allow both their high efficiency and intrinsic decorative appearance to operate to the maximum advantage. As has already been stated, combinations of tubes can be found to bring out the natural colours of almost any object in a way which cannot be attained by tungsten lighting, while the well known effect of apparent increased vitality which is obtained from the light of other electric discharge light sources is equally apparent in the case of these tubes. Already sufficient work has been completed in the lighting of shops with fluorescent tubes to indicate that their use is likely to revolutionise shop lighting practice in the very near future (figs. 18 and 19).

Fig. 18.—Osira fluorescent tubes provide 15 foot-candles of soft shadowless lighting in this store.

Some of the qualities of efficiency, colour and vitality that are claimed for fluorescent tube lighting can also be claimed for the T.O.T. system, modified for interior use. For this purpose suitable combinations of tungsten and Osira high pressure mercury lamps are blended in the interior lighting fittings. This can be done in a variety of ways ranging from a simple and inexpensive diffusing glass fitting taking two or more lamps of suitable wattage to the complete equipment of a laylight with lamps mixed in suitable proportions or a system of indirect Osira lighting combined with direct tungsten lighting.

SHOWCASE LIGHTING.

Before leaving the subject of interior lighting of shops, there are two subsidiary forms of lighting which are too important to pass over without reference. The first of these is the question of the provision of adequate lighting in counter display cases, showcases, etc. Apart from the fact that such illumination tends to give life to the whole of the interior of the shop, it enables the interior showcases to take the place of additional windows for the reason that they attract the prospective purchaser's eye to all sorts of goods which might otherwise have been overlooked.

Owing to the limitations of depth and lack of facilities for concealment, this class of lighting usually has to be done with striplite lamps in an ornamental reflector, but in larger showcases small reflectors, of a type similar to those used for shop window lighting, can sometimes be employed, and in other cases reflectors of this type can be mounted above the top of the showcase, concealed, if necessary, behind ornamental moulding and shining down through a glass top (fig. 20). If such a system is adopted in instances where goods are arranged on shelves, it is essential that the upper shelves should be well set back, or that all shelves should be made of glass,

Fig. 19.—Another example of Osira fluorescent tube lighting which brings out the natural colours of the fruit and flowers in the Coventry Street Corner House of J. Lyons & Co., Ltd.

otherwise obviously no light will penetrate from the top of the case to the lower shelves.

As an alternative, fittings comprising a striplite lamp and metal shield can be clipped on to each shelf, the metal shield serving the double purpose of throwing the light on to the goods and, by means of a cut-out stencil, providing a display notice. Architectural lamps can be used for a similar purpose, and instead of using a metal reflector, the lamp itself can be provided with a transparent cover on the back on which a display notice is written. In the case of wall cases and display shelves, lighting through diffusing glass panels set in the top, bottom or sides is an effective alternative (fig. 21).

The risk of overheating goods displayed in showcases is also often a problem, and in such instances the use of Osira fluorescent tubes provides a solution, for they are even smaller in bulk than striplite lamps and dissipate far less heat per unit of length while still providing adequate light.

The other form of auxiliary lighting which must be mentioned is the provision of internal signs. Apart from illuminated counter and display signs, it is essential, in the up-to-date shop, that adequate notice should be displayed to guide customers from one department to another. For this purpose illuminated signs are the ideal form of equipment.

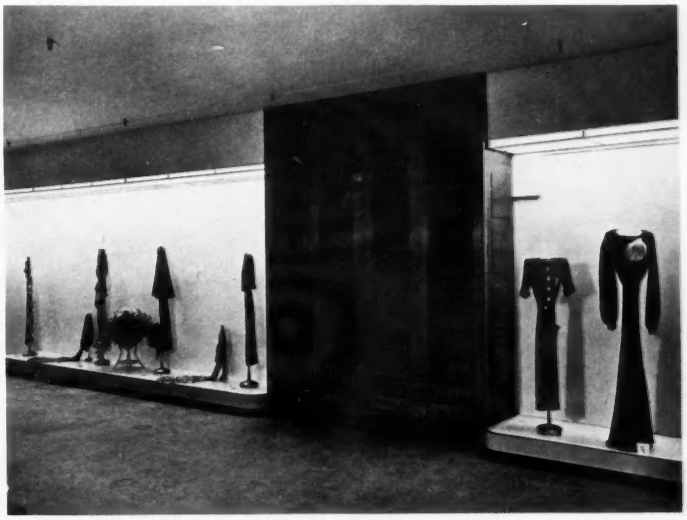


Fig. 20.—An example of overhead lighting applied to the display cases built into a wall in the Oxford St. showrooms of D. H. Evans & Co., Ltd., London.

Fig. 21.—A display of china on glass shelves is effectively illuminated by means of lamps behind diffusing glass panels.

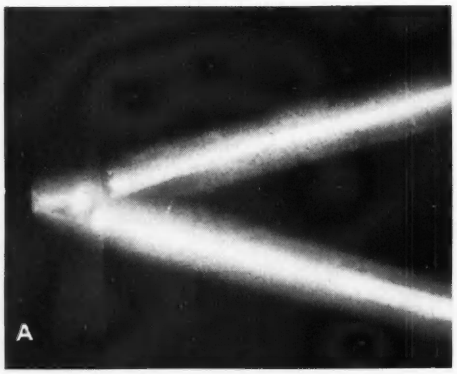
CHOICE OF EQUIPMENT.

An article on shop lighting would not be complete without some reference to the points which should be considered when choosing lighting equipment. First cost is relatively unimportant as the money expended in current consumption, lamp replacement, cleaning and other maintenance charges during the life of the fitting is likely to be many times that spent on the fitting in the first instance. The importance of flute design in relation to mirror glass shop window reflectors has been discussed previously in this Journal, and it was shown that relatively small apparent alterations in the depth and pitch of the flutes, such as to the layman might seem to be matters of appearance only, might make a considerable difference both to the overall efficiency and degree of light control of the reflector (fig. 22).

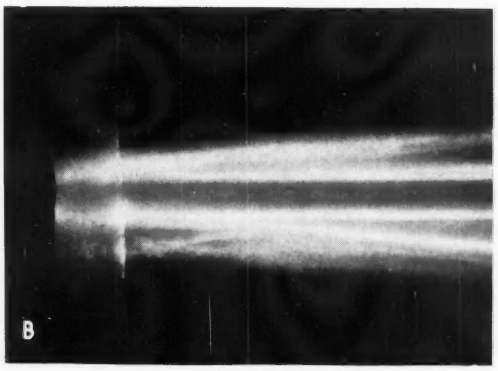
Equally the quality of the reflecting surface is of vital importance. Not only must the initial reflection factor be as high as possible but the reflecting surface must be proof against deterioration. Even where the silvering, in the case of glass reflectors, appears to be untarnished, the glass itself, if of bad quality, will tend to absorb more and more light as the months pass without any obvious change in the appearance of the reflector as a whole. In the case of diffusing glass fittings the overall efficiency of two apparently similar glasses may vary by 30 per cent or more, while glasses unevenly blown will allow the filament to be seen through them. Other points of importance in selecting opal glass enclosed units are to ensure that the glass is properly

annealed and will not crack of its own accord in service and that the globes are symmetrically blown and the necks cracked off so that the glasses will hang evenly. Finally it must be remembered that lamps have to be replaced and much time can be wasted in this process and in cleaning unless the fittings are designed with the question of maintenance ever in view.

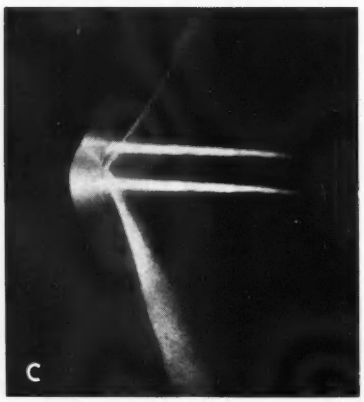
The relative importance of efficiency and the decorative appearance in any particular case is one which must be judged on its merits, but for any given standard of decorative effect it is obviously desirable to obtain the maximum result for the least expenditure in running cost. Elaborate decorative fittings may be less efficient and more costly to maintain than simple less decorative equipment, but by proper optical and mechanical design, this efficiency can be brought to the maximum possible with the system employed.



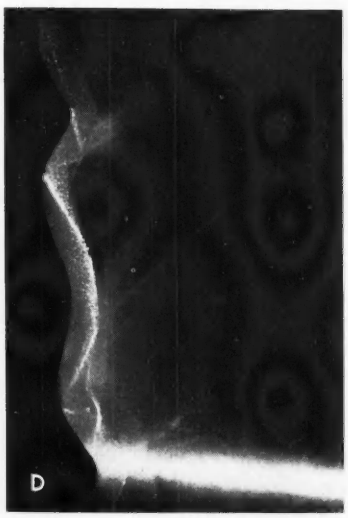
A—The incident ray emerges from the flute of the reflector as sharply defined as when it entered.



B—The adjacent reflected rays diverge only to the degree required in order to avoid striation.



C—With a badly designed flute, adjacent reflected rays diverge so greatly as to nullify all light control.



D—The ray is here trapped within the glass wall, never to emerge at all.

Fig. 22.—Illustrating A, B, the proper control of a light beam and C, D, the collapse of the beam with good and faulty types of mirror glass reflector.

Coal Handling Plant on the Lunghai Railway.

By G. F. WHITEWAY

Fraser & Chalmers Engineering Works of the G.E.C.

Fig. 1.—General view of the power house on the Yellow River, China.

THE construction of the important Lunghai Railway of China (which at the time of writing is one of the main objectives of the Japanese forces in China) has been directly and indirectly responsible for much of the industrial development of China in recent years. The need for adequate shipping facilities at suitable ports connecting with the railway was early recognized as being of extreme importance. Thus the development of the port of Lian Yuen, at the junction of the railway with the Yellow River has provided a means of receiving coal by railway from an important group of mines, storing it and exporting it direct *via* the river in ocean going vessels.

The scheme originally planned for a complete self-contained coal intake, handling, storing and shipping plant, having its own electrical power derived from steam plant, was adopted in 1934, and the contract for the supply and erection of such a plant, together with a power station and wharf facilities, was awarded to The General Electric Co., Ltd., the mechanical and structural portions of the work being undertaken by the company's Fraser & Chalmers Engineering Works. It is proposed in this article briefly to describe the equipment installed.

POWER STATION PLANT.

Two 700 kVA turbo-alternators are installed in the power station (fig. 1), each consisting of a high-pressure impulse turbine running at 6,500 r.p.m. and driving through reduction gearing a 3,300 volt, 3 phase, 50 cycle, 1,500 r.p.m. alternator (fig. 2). The turbines are supplied with steam at an admission pressure of 192 lbs. per sq. in., and at a temperature of 635°F. The turbines exhaust into surface condensers mounted in the basement below the turbines, and the circulating and condensate extraction pumps are driven through gearing by an auxiliary turbine, the circulating water being re-cooled in spray cooling plant capable of dealing with 50,000 gallons per hour.

Steam is generated by two Babcock and Wilcox water tube boilers each having a heating surface of 1,790 sq.ft., and equipped with integral superheaters, mechanical chain

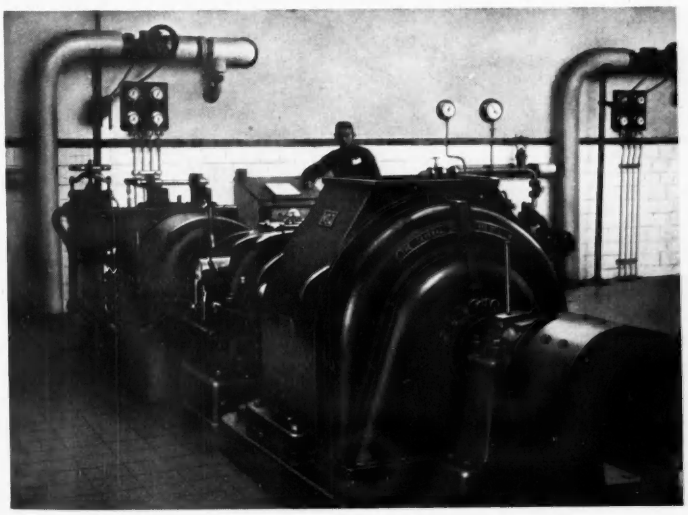


Fig. 2.—One of the two 700 kVA, 3,300 volt, 1,500 r.p.m. geared turbo-alternators installed in the power station.

grate stokers, economisers and induced draft fans.

For the control of the two alternators and five outgoing feeders, a 3,300-volt 7-panel sheet steel cubicle switchboard is installed (fig. 3), one of the feeders supplies a 380 volt flat-back switchboard

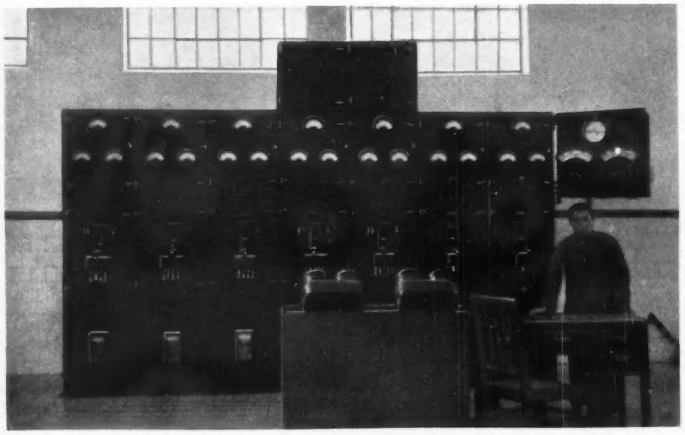


Fig. 3.—3,300 volt sheet steel cubicle switchboard controlling the alternators and feeders.

through the medium of a 125 kVA 3,300/380 volt transformer. This board controls the feeders to the various sub-stations and sub-distribution boards of the coal handling plant.

COAL STORAGE AND SHIPPING PLANT.

The comprehensive coal handling plant installed consists of a system of interconnected belt conveyors as shown in the diagram, fig. 4, with provision at one end of suitable means for receiving rail borne coal, and at the other end, for loading the coal into ships, with ample storage facilities between these points. The plant is designed to deal with run-of-mine coal at a maximum rate of 400 tons per hour, delivering it either into storage, from train to ship or from storage to ship. The railway wagons in which the coal arrives are of wood or steel construction, ranging in capacity from 10 to 40 tons. Each train as it arrives is shunted on to a track adjacent to the ingoing end of the plant and leading to a 60-ton Marshall wagon tippler. The coal wagons are then uncoupled and separately hauled by electric capstan into the tippler which empties them, after which an electric capstan hauls the empty wagons on to a tail track, whence they are later hauled away by locomotive.

WAGON TIPPLER

The arrangement and operation of the wagon tippler are illustrated in figs. 5 and 6. It is of interest that this tippler is the largest ever manufactured in this country, and is capable of handling a 42ft. 8in. wagon with a content weighing 40 tons and a tare of 18 tons. It is thus rated as a 60 ton machine. Special consideration has been given to the design of the tippler to make it suitable for handling wagons of rather light construction such as

Fig. 5.—60-ton Marshall wagon tippler erected for tests at Fraser & Chalmers Engineering Works.

Fig. 6.—60-ton Marshall wagon tippler shown in its fully tipped position.

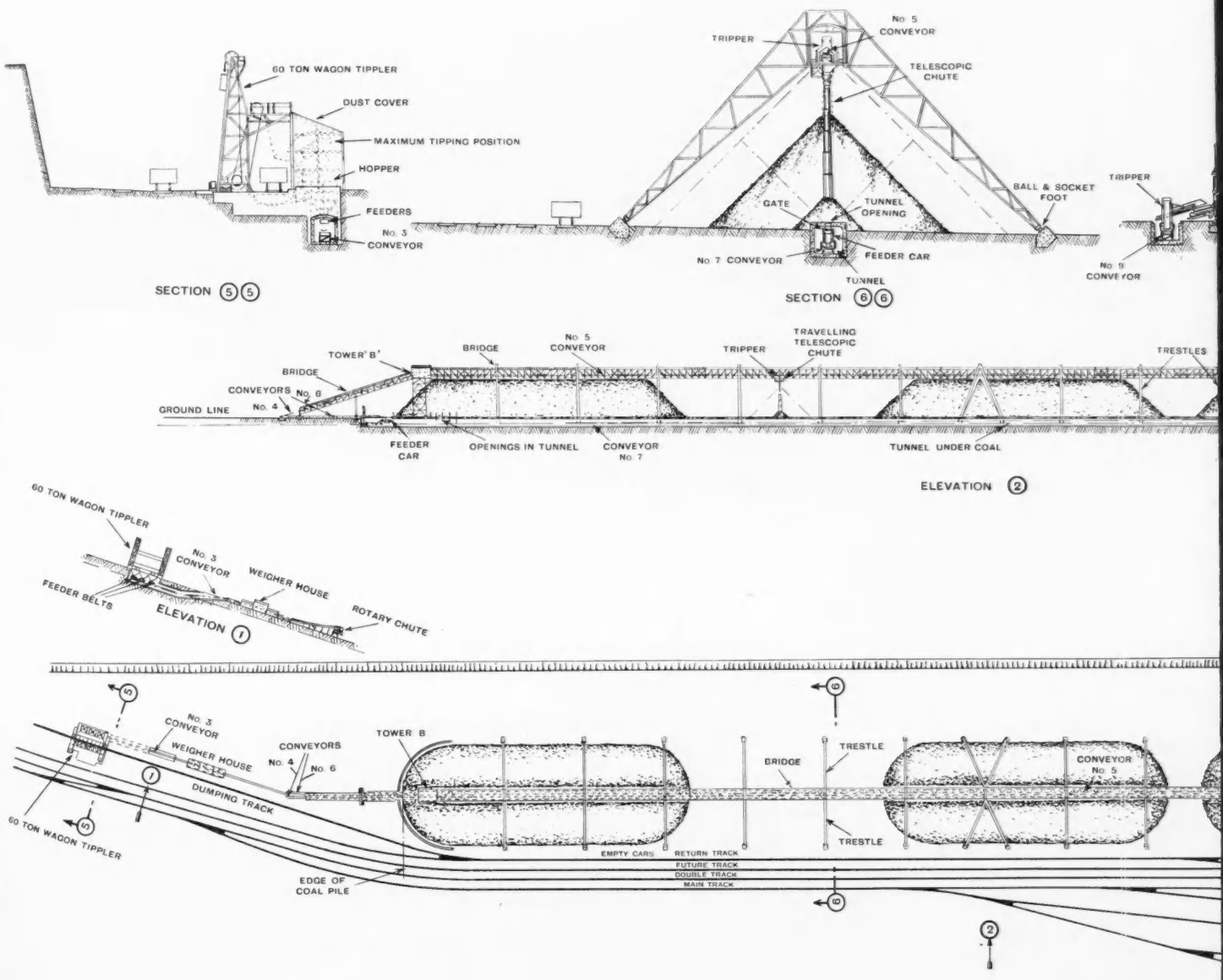
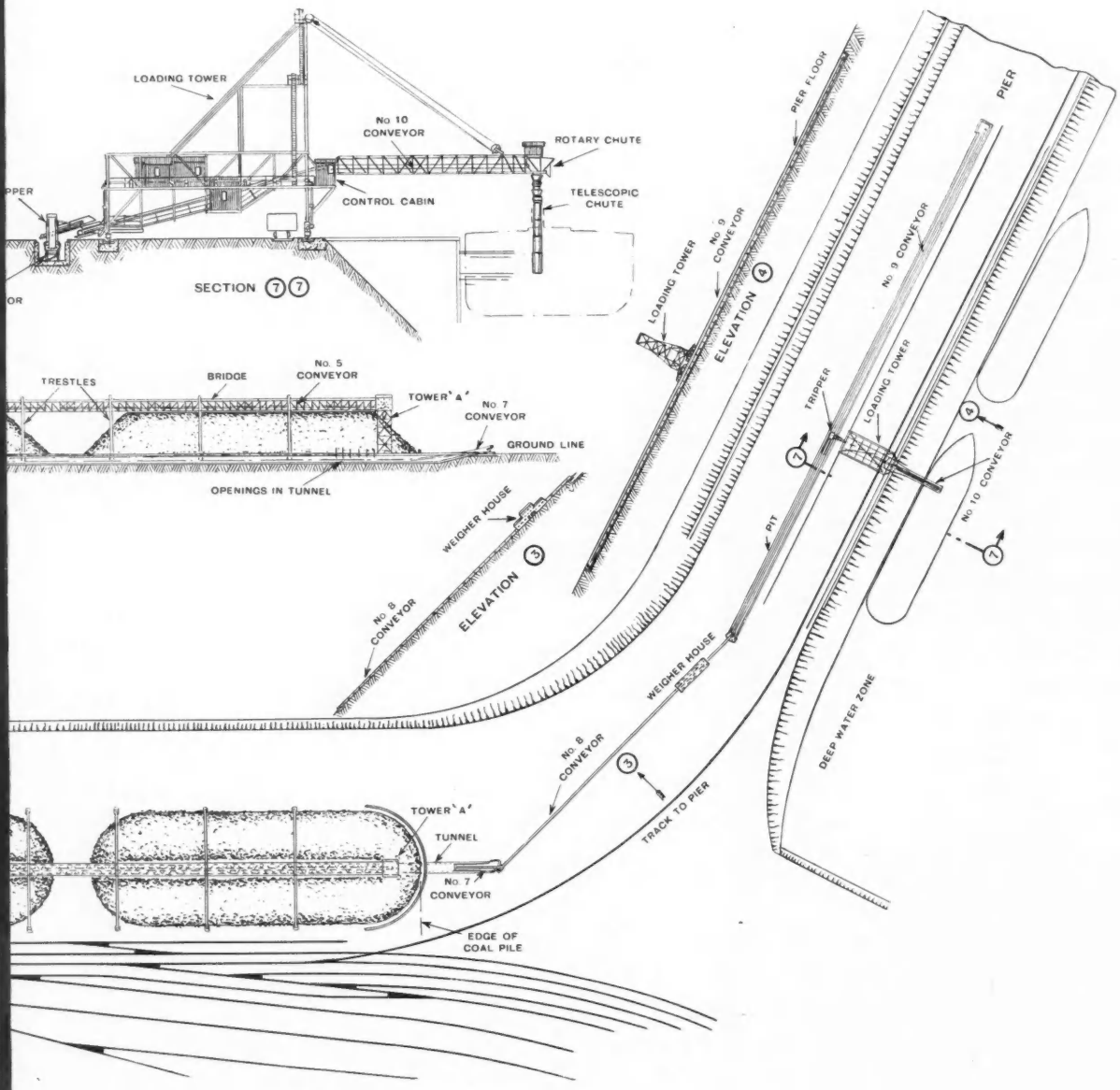


Fig. 4.—General arrangement of coal handling plant on the Lunghai Railv



nghai Railway, at the port of Lian Yuen, China.

are used on the Lunghai Railway without causing them any damage.

The tippler briefly comprises a wagon platform mounted on two hinged arms. The platform is raised and turned over by steel ropes connected to a double-barrelled counter-balanced winch mounted on a steel frame at a suitable height above the wagon platform. The full wagon is hauled on to the platform and centred in position. The winch is then started and the platform immediately begins to move laterally forward on rollers until the side of the wagon rests against a longitudinal spring-loaded bolster built integrally with the hoisting arms. The side thrust of the wagon is thus taken off the wheel flanges.

The hoisting and turning over movements continue until the wagon has turned through 90° when the top of the wagon engages with a number of vertical arms which effectually clamp the wagon between themselves and the platform, and allow the wagon to be turned over safely to its final emptying position. As soon as the wagon is completely emptied, the operation of the winch is reversed and the platform with the empty wagon returns to its normal position. The wagon is then hauled away to make room for the next full wagon.

The complete cycle of operation of the tippler as described above occupies a period of 90 seconds. A further 90 seconds are required to change the wagons, thus giving the equipment a handling capacity of 20 wagons per hour during continuous working.

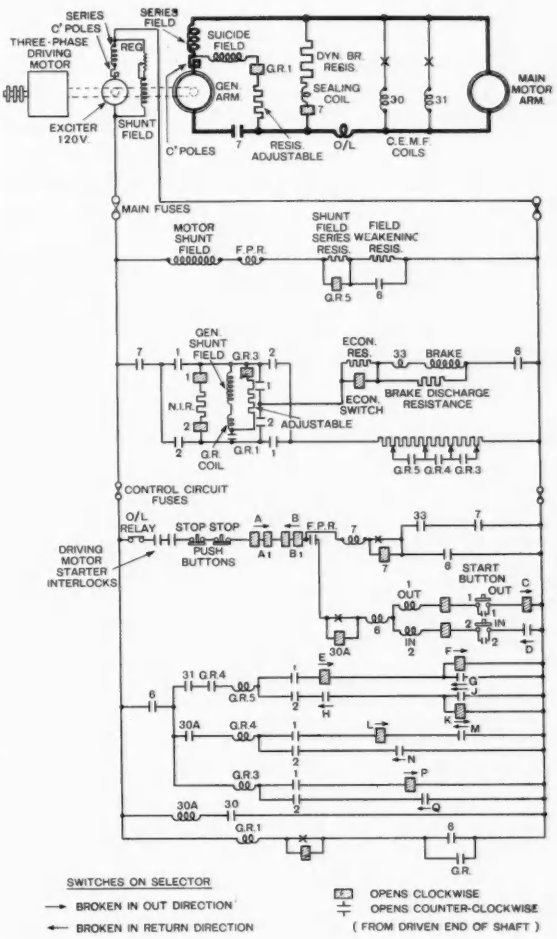
The tippler is operated by a 75 h.p. 230 volt, D.C. motor supplied with current from a 65 kW motor-generator set. The control gear is of the contactor type and this, together with the protective relays, are housed in a sheet steel cubicle on the top of which is mounted a dynamic braking resistance. A diagram showing the circuit arrangements of the control gear is shown in fig. 7.

COAL CONVEYING SYSTEM

The coal is emptied from the wagon into a large receiving hopper built in front of the wagon tippler whence it is drawn by three belt feeders at a uniform rate of 400 tons per hour, and fed to the first of a series of belt conveyors designated No. 3 in fig. 4, which leads to the storage ground or to the ship as required.

The No. 3 belt conveyor rises out of the tunnel under the feeder belts, and is provided at ground level with an automatic continuous belt weigher which automatically weighs and records all coal received from the tippler.

The coal is discharged over the head end of No. 3 conveyor on to either the main storage feeding belt conveyors Nos. 4 and 5, or to a short connecting belt conveyor No. 6, which leads to the second of the main trunk line conveyors No. 7 running through a tunnel under the storage ground. The No. 4 conveyor rises and delivers to No. 5 conveyor which



X OPERATING COIL SERIES RESISTANCES
7 MAIN LOOP CONTACTOR
1 } GEN. FIELD REVERSING CONTACTORS
2 } MECHANICALLY INTERLOCKED
6 COMMON CONTACTOR
G.R.5, G.R.4, G.R.3 ACCELERATING CONTACTORS (GEN. FIELD CIRCUIT)
G.R.1 SUICIDE FIELD CONTACTOR
30, 30A ACCELERATING AND ANTI-PLUGGING RELAYS
31 ACCELERATING RELAY
F.P.R. MOTOR FIELD PROTECTIVE RELAY
G.R. GEN. FIELD RELAY
33 BRAKE INTERLOCKING RELAY
A, B, C, D, E, F, G, H, J, K, L, M, N, P, & Q SELECTOR SWITCHES

OPERATIONS AS BELOW

OUTWARD TO TRIP

1 START "0" FT. ACCELERATE TO 20 FT./MIN.
2.M CLOSES 2'-6" " FROM 20 TO 54 FT./MIN.
3.F OPENS 21 FT. RETARD FOR FULCRUM CHANGE
4.G CLOSES 22 FT. POINT OF " "
22'-6" ACCEL. AFTER " "
5.E OPENS 34'-6" G.R.5 OUT, 33 FT./MIN.
6.L OPENS 35'-6" G.R.4 " 20 FT./MIN.
7.P OPENS 35'-9" G.R.3 " 12 FT./MIN.
8.C OPENS 36'-0" STOP
9.A OPENS 36'-3" OVERTRAVEL SWITCH

RETURN

1. START "0" FT. ACCELERATE TO 54 FT./MIN.
2.J OPENS 13 FT. RETARD FOR FULCRUM CHANGE
3.K CLOSES 14 FT. POINT OF " "
14'-6" ACCEL. AFTER " "
4.H OPENS 32'-3" G.R.5 OUT
5.N OPENS 33'-3" G.R.4 OUT
6.Q OPENS 35'-6" G.R.3 OUT
7.D OPENS 35'-11" STOP
8.B OPENS 36'-3" OVERTRAVEL SWITCH

A1 & B1 FINAL OVERTRAVEL LIMIT SWITCHES OPERATED BY MAIN BALANCE WEIGHT

Fig. 7.—Diagram showing the circuit arrangements of the control gear for the Marshall wagon tippler.

runs over the storage ground, shown in fig. 8, in which it will be seen that the storage conveyor is contained in a series of bridge spans carried on splayed trestle legs designed to clear the storage piles.

Fig. 8.—Storage ground and part of the coal handling plant. The travelling throw-off carriage operates along the belt conveyor on this bridge, delivering coal to the storage ground, which is 1,640 feet long and is capable of holding 160,000 tons of coal.

Coal is delivered on to the storage ground at any predetermined point by means of an automatic travelling tripper mounted on No. 5 conveyor. The tripper connects with a travelling telescopic chute which is connected to the bridge spans and travels along underneath them.

Coal is reclaimed from the storage ground through a number of gate openings arranged at intervals along the roof of the tunnel, and is fed to No. 7 tunnel conveyor by means of a travelling feeder car which runs along inside the tunnel. Means are provided on the feeder car for opening or closing the gates by power of any particular opening in the roof of the tunnel and coal is drawn through the gate for as long as required or until the pile over the gate is exhausted. When required No. 7 tunnel conveyor will also receive coal direct from the wagon tippler via No. 3 and No. 4 conveyors. No. 7 tunnel conveyor is intended solely to deliver

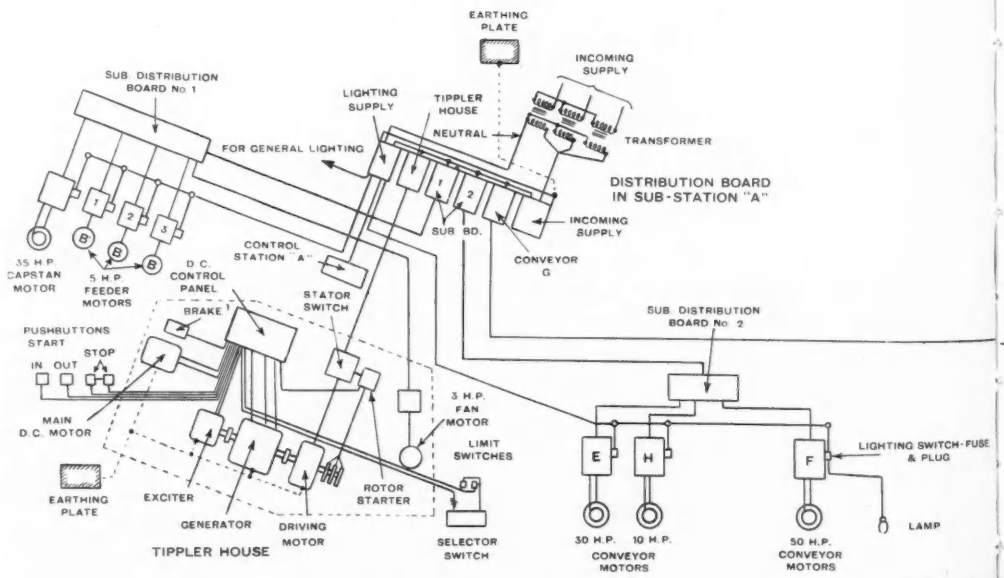


Fig. 9.—Diagram of connections showing control wiring between electrica

coal to the ships alongside the wharf via No. 8 and 9 conveyors and the travelling ship loading tower running along the wharf.

The No. 8 conveyor is provided towards its head end with a second automatic continuous belt weigher, which is intended primarily for recording the weight of coal drawn from the storage ground and delivered into the ships. No. 9 conveyor, which is fed from No. 8 conveyor, runs inside a trench (fig. 10), and is provided with a travelling throw-off carriage having a wing feeder conveyor which delivers coal on to the tail end of a boom conveyor carried in the travelling ship loading tower. The travelling ship loading tower, shown in figs. 11 and 12, runs along the length of the ship wharf and is provided with a hinged boom carrying the belt conveyor which receives coal from No. 9 conveyor, as described above. The boom, when not in use, can be hoisted up out of the way of ships moving alongside.

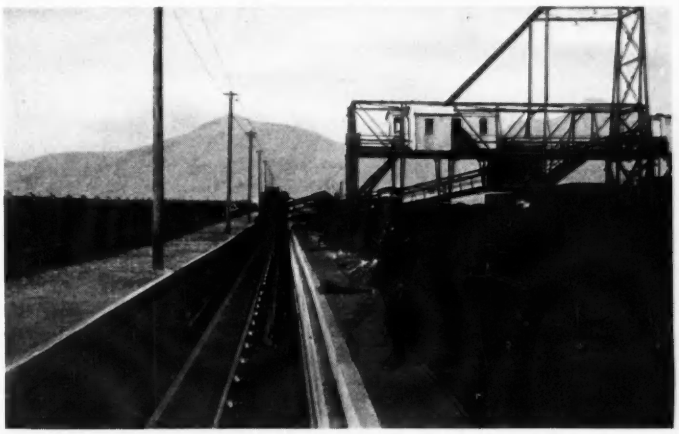


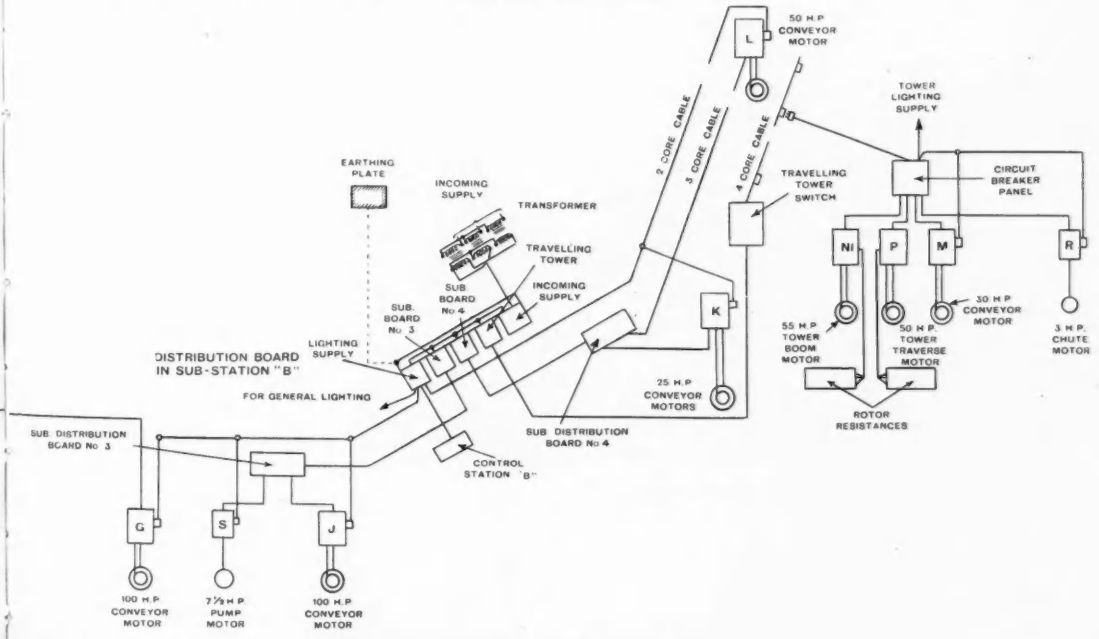
Fig. 10.—View of No. 9 coal conveyor running inside trench.

ELECTRICAL EQUIPMENT.

Motors totalling over 600 h.p. in capacity are employed in the driving of the coal handling equipment. The motors operate on a 350 volt 3 phase, 50 cycle, supply, and are remote controlled by means of contactor gear provided with a system of sequence interlocking so that it is impossible to start up conveyors in the wrong order.

Power for the coal handling plant is taken from the power station to two substations, known as Substation A and Substation B. Both substations contain a 6-panel industrial type switchboard controlling incoming and outgoing power feeders and lighting equipment. Substation A feeds the tippler, sub-distribution boards 1 and 2, and conveyor G (see fig. 9), while substation B feeds sub-distribution boards 3 and 4, and the travelling tower.

The contactor gear controlling the conveyor motors is of the air-break type, and is housed in dust and weatherproof cases. The gear is arranged to operate in conjunction with remote control push buttons and the acceleration of the motors from starting is controlled by timing relays. Each starter



Electrical equipment in the substations, tippler house and coal conveying plant.

is provided with an externally operated isolating switch and sequence interlocking contacts; also cutout switches for providing local control, together with switch plugs for inspection lamps.

Remote control is arranged as follows:—Two push button control stations are provided to give the correct sequence of starting the conveyors. Control station A is situated near substation A, and control station B near substation B. Control station A is arranged to start motors H, E and B in that order (see fig. 4) by the pressing of a single push button. This action will start the conveyors taking the coal from the tippler to the storage ground in the correct order. The pressing of a second push button starts motors G, F, E, B, in that order, if it is required to start the conveyors taking coal through the tunnel. It should be noted that a coal chute is provided between conveyors H and G which actuates a limit switch and so determines the sequence in which these two conveyors will be started.

Control station B starts the motors L, K, and G, in that order from a single push button, but these motors will start only when motor M (mounted in, and controlled from, the loading tower) is running. Signal lights in the tunnel are also operated from control station B, and inform the operators in the tunnel when to open and close the coal feeding gates previously mentioned. Indicating lamps also show which conveyor sequence is operating.

Fig. 11.—View of ship loading pier from the end tower of No. 5 conveyor.

The travelling ship loading tower is supplied with current through a flexible cable and 6-point plug which can be inserted into any one of twelve sockets situated along the quayside. This enables the tower to take up any convenient position. The supply from the socket is taken to a protective panel fitted with isolator, circuit breaker and overload relays. Thence the supply is fed to two drum controllers for the boom hoist and traverse motors, and also to a reversing contactor starter controlling the motor operating the telescopic chute which feeds coal into the hold of the ship.

In conclusion, it should be mentioned that the contract included all the lighting equipment required for the power station and coal handling plant and all the cabling and wiring.

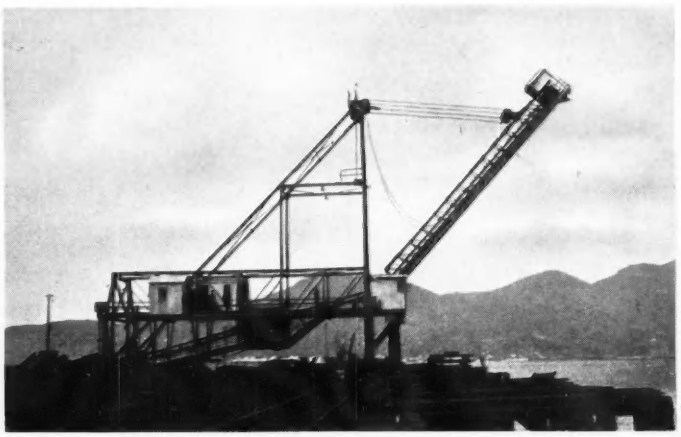


Fig. 12.—Travelling ship-loading tower which runs along the length of the ship wharf.

Technical Literature.

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS BY MEMBERS OF THE STAFF OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

SOME PROPERTIES OF ROLLED MOLYBDENUM SHEET*.

By C. E. Ransley and H. P. Rooksby (G.E.C. Research Laboratories).
J. Inst. Metals, Vol. 3, pt. I, p. 29, January, 1938.

It was found that molybdenum sheet rolled successively in two directions at right angles exhibited a remarkable form of brittleness, therefore an investigation of the crystal orientation and some qualitative mechanical tests were made on molybdenum sheets prepared by different rolling procedures.

ELECTRON PUMP EFFECT AT HIGH FREQUENCIES*

By M. R. Gavin (The M.O. Valve Co., Ltd. and the G.E.C. Research Laboratories).
Wireless Engineer, XV., No. 173, p. 81, February, 1938.

A theory is derived to explain the phenomenon that electron current may flow to the anode of a triode when an H.F. alternating potential is applied to the grid and a negative potential to the anode. Calculated electron paths are shown diagrammatically, and the theory is shown to be in good agreement with experimental observations.

DOMESTIC ELECTRIC COOKERS*.

By O. W. Humphreys (G.E.C. Research Laboratories).
Jour. I.E.E.

Reprinted in Vol. IX, No. 1, and in this issue of the G.E.C. Journal.

THE APPRAISEMENT OF LIGHTING*.

By C. C. Paterson (G.E.C. Research Laboratories).

The Guthrie Lecture delivered before the Physical Society, October, 1937.
Reprinted in Vol. IX, No. 1 of the G.E.C. Journal.

INAUGURAL ADDRESS TO THE PUBLIC LIGHTING SECTION OF THE ILLUMINATING ENGINEERING SOCIETY*.

By C. C. Paterson (G.E.C. Research Laboratories).
Trans. I.E.S. (London), December, 1937.

An outline of the scope and purpose of the section and some of the problems confronting it.

SOME PROPERTIES OF NEGATIVE FEEDBACK AMPLIFIERS*.

By L. I. Farren (G.E.C. Research Laboratories).
Wireless Engineer, XV. No. 172, p. 23, January, 1938.

Various methods of applying negative feedback thermionic amplifiers are discussed, together with the modifications to the amplifier characteristics produced thereby. Methods of design are given, whereby the maximum possible amount of feedback may be applied without causing self oscillation. The use of "matrix" algebra for circuit analysis is outlined with particular application to the problems of negative feedback.

THE APPLICATION OF MODERN ELECTRIC LAMPS TO STREET LIGHTING*.

By G. H. Wilson (G.E.C. Research Laboratories).
Assoc. Pub. Lighting Engineers, Folkestone, 1937.

In the first part of the paper, results are given of recent investigatory work on the planning of installations. The production of natural appearance under artificial lighting is discussed and the influence of post position and height on the appearance of an installation as shown by experimental results is described in detail. Constants are given for an optimum installation as deduced from the results of the experimental work. The second part of the paper deals with new designs of lighting unit for existing lamps, and in fittings for use with them. Details are given of the new horizontal burning 250 watt and 400 watt high pressure mercury vapour lamps, the 80 watt and 125 watt high pressure mercury vapour lamps, and the 400 watt luminescent powder lamp. Particulars of the design and performance of these new lamps in recently designed fittings are also given.

A DIRECT READING PHOTOELECTRIC TRICHROMATIC COLORIMETER*.

By G. T. Winch and E. H. Palmer (G.E.C. Research Laboratories).
Trans. I.E.S. (London) Vol. XI., No. 10, Oct., 1937.

Details are given of the principle, development and construction of a new type of photoelectric colorimeter, which indicate the trichromatic coordinates directly on an R.G.B. system closely and linearly related to the C.I.E., XYZ system. The method of calibration is described, and the appendix contains a worked example of the transformation from the R.G.B. to the XYZ system, together with a nomogram for the rapid conversion from one system to the other. Reference is made to the many applications of this instrument.

THE GRÜNEWALD BRIGHT-ANNEALING PROCESS*.

By S. V. Williams (G.E.C. Research Laboratories).
Metal Treatment, Summer 1937.

The original Grünewald bright-annealing process was an ingenious method of preventing oxidation without the use of an artificial atmosphere by applying the principle of the fruit preserving jar to the electric annealing furnace. Experience has shown, however, that in certain applications advantages are obtained by the use of artificial atmospheres and a modified process has therefore been developed. Both processes are described and their applications to a number of metals discussed.

THE HUMAN ELEMENT.

By F. Horler (The Siemens and General Electric Railway Signal Co. Ltd.)
Inst. Railway Signal Engineers.

The effect of the "human element" as associated with railway signalling is discussed. The author shows why railway signalling requires the use of equipment having the greatest possible reliability.

RELAY INTERLOCKING.

By A. J. Golding (The Siemens and General Electric Railway Signal Co., Ltd.)
Inst. Railway Signal Engineers.

The paper deals with a recently introduced system in which the electrical interlocking of points and signals, in conjunction with track circuit controls, is achieved by means of relays instead of the well-known miniature lever frame, thus permitting the signalman's controls to be fixed on a geographical layout of the station concerned, the whole of the contact equipment being placed at a convenient location nearby.

*** A limited number of reprints is available; copies may be obtained on application to the Editor, G.E.C. Journal, Witton Engineering Works, B'ham, 6.**

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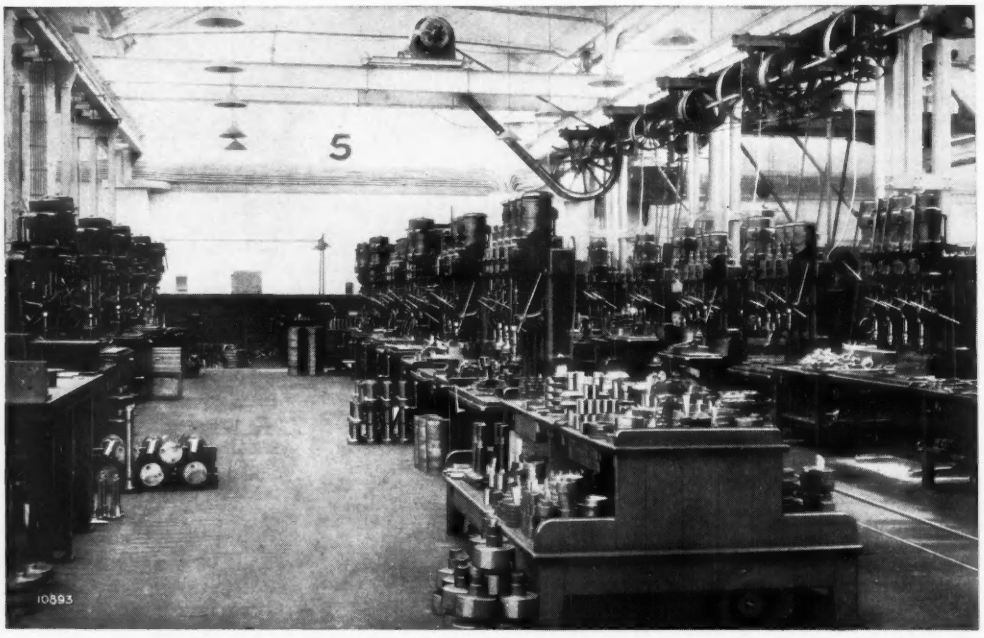

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